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Monsanto Research Corp, Dayton, Ohio

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Water Pollutants From Coal Storage Areas

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16. ABSTRACT

This report describes a study of water pollution levels that result from coal stockpiles maintained outdoors. A representative source was defined to characterize the pollution levels. Effluent data was obtained by placing coals, collected from various regions in the U.S., under a rainfall simulator. Drainage samples were analyzed for water quality parameters, organic and inorganic substances, and pollutants covered by effluent limitations. Coal drainage effluent concentrations, rates, and factors were determined. Hydrologic relationships were used to calculate the diluted concentrations entering a waterway. The ratio of this level to water quality criteria was determined as an indication of the potential environmental impact.

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ERRATA SHEET

Pg. 2, 2nd paragraph, line 1 - "from one to seven" should be "generally several"

2nd paragraph, line 6 - "6 to 11" should be "3 to 8"

Pg. 3, Table 1 - The diluted concentration column numbers should be multiplied by 48.8 with the exception of Iron, BOD$_5$, COD, Nickel, Total organic carbon, pH, and the last six chemicals. Iron should be multiplied by 24.4. Nickel and Total organic carbon are multiplied by 488 and the bottom six chemicals are multiplied by 3.6.

Pg. 48, 6th paragraph, line 6 - "610" should be "608".

line 6 - delete remainder of paragraph starting with Therefore. Substitute the following 2 sentences. The diluted concentration, due to area runoff, would be calculated by multiplying the concentrations in Table 19 by fifteen percent of the 21 m^3/hr striking the pile and dividing by the total runoff (608 m^3/hr + 21 m^3/hr). These concentrations are given in Table 29.

Pg. 51, Table 29 - Multiply all values by 48.8 except for Iron, Nickel and Total organic carbon. Multiply Iron by 24.4. Multiply Nickel and Total organic carbon by 488.

Pg. 52, 2nd paragraph, line 3 - "Table 22" should be "Table 23."

Table 30 - multiply all values by 3,600.

Pg. 60, Table 35 - Multiply all values in Runoff concentration and C_R/C_H ratio columns by 48.8 except for Nickel (Multiply these by 488). Superscript a reference to asbestos instead of arsenic.

Table 36 - Multiply all values in columns 1 and 3 by 48.8.

Pg. 61, Table 37 - Multiply all values in columns 1 and 3 by 3,600.

Pgs. 68, 69, and 71 - equation numbers should be 10 thru 17 with corresponding changes in the text.

EPA-600/2-78-004m
May 1978

SOURCE ASSESSMENT:
WATER POLLUTANTS FROM COAL STORAGE AREAS

by

R. A. Wachter and T. R. Blackwood
Monsanto Research Corporation
Dayton, Ohio 45407

Contract No. 68-02-1874

Project Officer

John F. Martin
Resource Extraction and Handling Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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1-B

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of water pollutants from coal storage areas. This study was conducted to provide a better understanding of the distribution and characteristics of water pollutants from coal storage areas. Further information on this subject may be obtained from the Extraction Technology Branch, Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, or uneconomical, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include: process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number of operations (more than 500) in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries that represent sources of pollutants in accordance with EPA's responsibility. Dr. Robert C. Binning serves as MRC Program Manager in this overall program, entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. Reports prepared in this program are of two types: Source Assessment Documents, and State-of-the-Art Reports.

Source Assessment Documents contain data on pollutants from specific industries. Such data are gathered from the literature, government agencies, and cooperating companies. Sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source pollutants. These documents contain all of the information necessary for IERL to decide whether a need exists to develop additional control technology for specific industries.

State-of-the-Art Reports include data on pollutants from specific industries which are also gathered from the literature, government agencies and cooperating companies. However, no extensive sampling is conducted by the contractor for such industries. Sources in this category are considered by EPA to be of insufficient priority to warrant complete assessment for control technology decisionmaking. Therefore, results from such studies are published as State-of-the-Art Reports for potential utility by the government, industry, and others having specific needs and interests.

This State-of-the-Art Report contains data on water pollutants from coal storage areas. This study was completed for the Extraction Technology Branch of the Resource Extraction and Handling Division, IERL-Cincinnati. Mr. John F. Martin served as EPA Project Leader.

ABSTRACT

Coal stockpiles maintained outdoors at production and usage sites emit effluents due to leaching and drainage during and after precipitation. Aquatic lifeforms are exposed to these effluents as the runoff flows from the drainage area into waterways. This report quantifies the effluent levels from these sources by examining coals (both freshly mined and aged) from six coal regions of the United States. A representative source is defined to help characterize the wastewater level from coal storage areas. Effluent data were obtained by subjecting coals to rainfall beneath a simulation apparatus and collecting grab samples of the wastewater. The samples were analyzed for organic and inorganic substances and water quality criteria parameters. Hydrologic relationships were used to estimate the runoff concentrations. Water quality criteria concentrations are compared with these levels to estimate their potential environmental impact. Applicable and future control techniques are discussed along with the growth and nature of stockpile quantities retained at facilities.

This report was submitted in partial fulfillment of Contract No. 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. The study covers the period November 1976 to December 1977, and the work was completed as of December 1977.

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ABBREVIATIONS AND SYMBOLS

A -- Appalachian coal
Ad -- area of drainage basin minus pile area
AMD -- acid mine drainage
AP -- sampling pan surface area
BATEA -- best available technology economically achievable
BOD_5 -- 5-day biochemical oxygen demand
BOD_L -- BOD at $x = 0$
BOD_{Lx} -- BOD loading at distance x
BPCTCA -- best practicable control technology currently available
C -- coefficient of runoff
C_H -- hazardous concentration
C_k -- concentration levels for each effluent parameter, k
COD -- chemical oxygen demand
C_R -- runoff concentration
DiOP -- Di-iso-octylphthalate
Do -- annual days of operation
$\overline{Do}$ -- average days of operation
DO_C -- critical dissolved oxygen deficit
$\overline{Doi}$ -- average annual days of operation for user type, i
DO_M -- dissolved oxygen content of the stream and coal pile runoff mixture
DO_O -- initial dissolved oxygen deficit in the runoff and stream mixture
DO_S -- saturation concentration of dissolved oxygen
DO_W -- stream oxygen content before receiving runoff
Ds -- days of supply
$\overline{Ds}$ -- average days of supply
$\overline{Dsi}$ -- average days of supply for user type, i
H -- pile height
iR -- rainfall intensity
$\overline{IR}$ -- average rainfall intensity
iRP -- weight of coal subjected to the simulation rainfall
IE -- Interior-eastern coal
IW -- Interior-western coal
k -- effluent parameter
K' -- BOD rate constant
K'_2 -- reaeration constant

LC_{50} -- lethal concentration to 50% of tested species
LD_{50} -- lethal dose to 50% of tested species
L_{fk} -- leaching factors
N -- number of sources per user type
NP -- Great Northern Plains coal
NDL -- no detectable level
$\bar{P}_k$ -- average percent of the element in coal
Qe -- effluent rates
$\bar{Q}r$ -- average rate of runoff
s -- weight of coal sample in simulator pan
Sp -- surface area
SW -- Southwestern coal
Tc -- total quantity of coal stored in United States
TLV -- threshold limit value
TOC -- total organic carbon
TSS -- total suspended solids
TVA -- Tennessee Valley Authority
V -- stream flow velocity
Vd -- drainage volumetric rate
V_r -- runoff flow rate
V_W -- waterway flow rate
W -- Western coal
$\bar{W}_k$ -- average weight of the element in the coal
x -- downstream distance
x_C -- distance at which DO_C occurs
X -- amount of coal stored
Xcij -- annual coal usage for user type, i, source, j
ρB -- bulk density of coal

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	To	Multiply by
Centimeter (cm)	Inch	0.394
Degree Celsius (°C)	Degree Fahrenheit	$t^\circ_F = 1.8\ t^\circ_C + 32$
Gram (g)	Pound-mass (lb mass avoirdupois)	2.204×10^{-3}
Kilogram (kg)	Pound-mass (lb mass avoirdupois)	2.204
Kilometer^2 (km^2)	mile^2	3.860×10^{-1}
Meter (m)	Foot	3.281
Meter (m)	Inch	3.937×10^{1}
Meter^2 (m^2)	Foot^2	1.076×10^{1}
Meter^2 (m^2)	Inch^2	1.550×10^{3}
Meter^3 (m^3)	Foot^3	3.531×10^{3}
Meter^3 (m^3)	Gallon (U.S. liquid)	2.642×10^{2}
Meter^3 (m^3)	Inch^3	5.907×10^{4}
Meter^3 (m^3)	Liter (ℓ)	1.000×10^{3}
Metric ton	Ton (short, 2,000 lb mass)	1.102
Pascal (Pa)	Pound-force/inch^2 (psi)	1.450×10^{-4}
Radian (rad)	Degree (°)	5.730×10^{1}

PREFIXES

Prefix	Symbol	Multiplication factor	Example
Kilo	k	10^{3}	1 kg = 1×10^{3} grams
Micro	μ	10^{-6}	1 μg = 1×10^{-6} gram
Milli	m	10^{-3}	1 mm = 1×10^{-3} meter
Nano	n	10^{-9}	1 nm = 1×10^{-9} meter

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[a] Metric Practice Guide. ASTM Designation E 380-74, American Society for Testing and Materials, Philadelphia, Pennsylvania, November 1974. 34 pp.

ACKNOWLEDGMENT

Monsanto Research Corporation wishes to acknowledge the cooperation of the Purdue University Department of Agricultural Engineering. A special note of appreciation is expressed to Dr. Lawrence Huggins for his assistance in our research efforts. This acknowledgement does not convey an endorsement by Purdue University of our research results.

SECTION 1

INTRODUCTION

This report investigates the water pollution levels that result from leaching, drainage, and runoff of coal stockpiles maintained outdoors. Geographical locations and coal quantities stored at user sites throughout the United States are first established. A representative source is thereafter defined to characterize the pollution levels. To obtain effluent data, coals were collected from various coal regions and placed under a rainfall simulator. Samples of the drainage were collected and analyzed for water quality parameters, organic and inorganic substances, and pollutants covered by effluent limitations. Coal drainage effluent concentrations, rates, and factors were determined, and hydrologic relationships were used to calculate the diluted concentrations entering a waterway. The ratio of this level to water quality criteria was determined as an indication of the potential environmental impact. Applicable controls for coal drainage effluents are established along with future control considerations. The change in stockpile quantities with time is projected, and the resultant effect on effluent levels is also quantified.

SECTION 2

SUMMARY

A total of 124 x 10^6 metric tons[a] (137 x 10^6 tons) of coal were stockpiled in the United States in 1975. A representative coal stockpile contains 95,000 metric tons (104,000 tons) of coal. This mass is subjected to an average rainfall intensity of 1.8 μm/s to 3.5 μm/s (0.25 to 0.50 in./hr) for 1 hr a day, every 2.6 days (139 days/ yr). Approximately 15% of this rainfall drains through the stockpile and produces the undiluted effluent concentration levels in Table 1. These effluents combine with runoff from the surrounding area to reach the nearest waterway over an average distance of 86 m (282 ft). An average of 629 m^3 of runoff flow each hour (22,210 ft^3/hr). This flow results in a dilution of the effluents drained from the stockpile to produce the diluted effluent concentrations in Table 1 that enter the nearest waterway.

The diluted values listed in the table are from one to seven orders of magnitude less than water quality criteria. These criteria were developed from 1) EPA water quality criteria or 2) data on subacute toxicities or lethal concentrations of substances as they affect aquatic species. Levels of selected toxic organic pollutants were from 6 to 11 orders of magnitude less than the criteria levels, after dilution. The effluent concentrations (shown in Table 1) were found to vary an average ±211% between sources and ±129% at a source.

At present, control technology is not generally applied at coal storage areas; however, effluent limitations have been established. These limitations are based on application of the best practicable control technology currently available, which is collection, neutralization, and sedimentation. Other control techniques are also available.

The amount of coal stockpiled at user sites has grown from 40.4 x 10^6 metric tons (44 x 10^6 tons) in 1940 to the present level of 124 x 10^6 metric tons. The current energy shortages and mining trends of the United States may increase coal storage

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[a] 1 metric ton equals 10^6 grams; conversion factors and metric system prefixes are presented in the prefatory material.

TABLE 1. DILUTED AND UNDILUTED EFFLUENT CONCENTRATIONS FROM A REPRESENTATIVE COAL STOCKPILE

Effluent	Concentration, g/m^3 Undiluted	Concentration, g/m^3 Diluted
Total suspended solids	1,551	0.16
Total dissolved solids	754	0.08
Sulfate	401	0.04
Iron	39	0.007
Manganese	0.69	7×10^{-5}
Free silica	10.1	0.001
Cyanide	<0.001	$<1 \times 10^{-7}$
BOD$_5$	<3.8	0.002[a]
COD	1,436	0.002[a]
Nitrate	0.31	3×10^{-5}
Total phosphate		
Antimony	4.6	4×10^{-4}
Arsenic	15.7	0.001
Beryllium		
Cadmium	0.002	2×10^{-7}
Chromium	0.004	4×10^{-7}
Copper	0.08	7×10^{-6}
Lead	0.06	6×10^{-6}
Nickel	3.1	4×10^{-5}
Selenium	19.9	0.002
Silver		
Zinc	0.8	7×10^{-5}
Mercury	<0.001	1×10^{-7}
Thallium		
Chloride	0.27	2×10^{-5}
Total organic carbon	280	0.003
pH[b]	6.78	6.9
2-Chloronaphthalene	0.014	2×10^{-5}
Acenaphthene	0.015	2×10^{-5}
Fluorene	0.014	2×10^{-5}
Fluoranthene	0.016	2×10^{-5}
Benzidine	0.014	2×10^{-5}
Benzo(ghi)perylene	0.044	7×10^{-5}

Note.—Blanks indicate no detectable level.

[a] Dissolved oxygen deficit at critical distance (BOD$_5$ results questionable).

[b] Logarithm of reciprocal of hydrogen ion concentration in g/m^3.

quantities to 229×10^6 metric tons (252×10^6 tons) in 1985 and 680×10^6 metric tons (750×10^6 tons) in the year 2000. Increases in stockpile quantities will average 3.8% (by wt) per year, with a corresponding increase in mass emissions.

SECTION 3

SOURCE DESCRIPTION

SOURCE CHARACTERISTICS

Coal is a mineral solid formed by the partial decomposition of vegetable matter under anaerobic conditions and varying degrees of temperature and high pressure. It is primarily organic matter composed essentially of carbon, hydrogen, oxygen, nitrogen and sulfur. Inorganic matter is present partly in the coal and primarily in the ash (1).

There are four ranks of coal, defined by the American Society for Testing and Materials as: anthracite, bituminous, subbituminous, and lignite (2). These classifications are derived from the ranges of volatile matter content and heating value. Anthracite has the highest heating value and lowest volatile matter content; the reverse is true of lignite.

The consumption of coal by rank in the United States is shown in Table 2 (3, 4).

All of these coals are mined from the earth primarily for use as fuel, but also for producing coke, coal gas, water gas, and many coal tar products (3, 4).

---

(1) Magee, E. M., H. J. Hall, and G. M. Varga, Jr. Potential Pollutants in Fossil Fuels. EPA-R2-73-249, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1973. 151 pp.

(2) A.S.T.M. Standards on Coal and Coke. American Society for Testing and Materials, Philadelphia, Pennsylvania, September 1948. pp. 80.

(3) Minerals Yearbook, 1973, Volume I. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1973. pp. 8-36.

(4) Bituminous Coal and Lignite Distribution, Calendar Year 1975 (Bituminous Coal and Lignite Distribution Quarterly). Mineral Industry Surveys, U.S. Department of the Interior, Washington, D.C., 12 April 1976. 51 pp.

TABLE 2. CONSUMPTION OF COAL BY RANK (3, 4)

Rank	Usage, 10^6 metric tons	Percent of total
Bituminous	289	60.4
Subbituminous	175.1	36.6
Lignite	8.6	1.8
Anthracite	5.8	1.2
TOTAL	478.5	100.0

At plants that use coal, operating costs are kept at their lowest level when consumption is constant. However, in order to meet fluctuations in demand, the extra coal is put into stock. This factor and other advantages compensate for the expenditures created in the stockpiling and removal from storage. In general practice, daily fluctuations in consumption are met by a small buffer storage pile. An intermediate stockpile is created to handle holiday or transport difficulties. A strategic reserve is built in the summer months to handle winter consumption levels (5). These stockpiles are maintained outdoors to facilitate handling. The specific method of stroage employed depends upon the coal rank, facilities available, and the likely length of storage time.

STOCKPILE LOCATIONS AND QUANTITIES

After coal is mined, approximately 50% is cleaned, sized, and stockpiled at preparation plants near the mine (1). None is stored at the mine itself because of U.S. Bureau of Mines regulations (6). Coal is transported to the user sites either directly from the mine, or from the preparation plants after processing.

The amount of coal placed in storage varies with the type of user. The three largest users of coal are 1) electric utility boilers, 2) industrial boilers, and 3) coke production plants. Stockpile size at these facilities is designated and established from the days of supply (Ds) available in storage and the annual days of operation (Do). Table 3 (7-9) lists the average days of supply ($\bar{D}s$) and average annual days of operation ($\bar{D}o$) for coal users.

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(5) Shipley, D. F. Coal Storage. Monthly Bulletin of the British Coal Utilisation Research Association, XXIII(11-Part II):433-446, 1959.

(6) Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio. (Final document submitted to the EPA by Monsanto Research Corporation, July 1977.) 96 pp.

TABLE 3. AVERAGE DAYS OF SUPPLY ($\bar{D}s$) AND AVERAGE ANNUAL DAYS OF OPERATION ($\bar{D}o$) FOR COAL USERS (7-9)

User	Average days of supply, $\bar{D}s$	Average annual days of operation, $\bar{D}o$
Electric utility boilers	85 (7)	365 (8)
Industrial boilers	48 (7)	205[a]
Coke production plants	37 (9)	365 (9)
Steel and rolling mills	40 (7)	250[a]
Preparation plants	10[a]	250[a]

[a] MRC estimate, based on industrial experience.

The total quantity of coal stored in the United States (Tc) is computed from the product of the ratio $\bar{D}s/\bar{D}o$ and the annual usage of coal (Xc) per user type, i, and source, j, from Equation 1:

$$Tc = \sum_{i=1}^{5}\left(\sum_{j=1}^{N}\frac{\bar{D}si}{\bar{D}oi}\cdot Xcij\right) \qquad (1)$$

where $\bar{D}si$ = average days of supply for user type, i

$\bar{D}oi$ = average annual days of operation for user type, i

Xcij = annual coal usage for user type, i, source j

Tc = total quantity of coal stored in the United States

N = number of sources per user type

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(7) Production of Coal - Bituminous and Lignite, 1976, Per Week. Weekly Coal Report No. 3060, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., May 7, 1976. 4 pp.

(8) FPC Issues Electric Fuel Consumption, Stocks. News Release No. 20499, Federal Power Commission, Washington, D.C., 22 July 1974. 3 pp.

(9) Coke and Coal Chemicals in August 1976. Coke and Coal Chemicals Monthly, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., August 1976. 2 pp.

Using Equation 1, coal usage data (10-13) (updated by Appendix A), and Table 3, it is determined that over 124 x 10^6 metric tons of coal are stockpiled at greater than or equal to 950 coal user sites (10-13).

GEOGRAPHICAL DISTRIBUTION

There were 535 x 10^6 metric tons of coal produced and 478.5 x 10^6 metric tons of coal consumed in the United States in 1975 (4). The percent breakdown of coal consumption by users is presented in Figure 1.

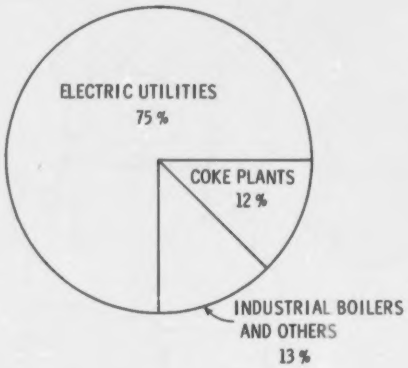

Figure 1. Breakdown of coal consumption by users, 1975 (4).

The distribution of coal usage and storage per state is illustrated in Figure 2. The numerical quantities of coal stored per state are listed in Table 4 (4, 14, and personal communication with Ms. Williams, U.S. Bureau of Mines, Division of Fossil Fuels, Washington, D.C., 6 December 1976). Detailed data pertaining to coal quantities consumed and stored per user and coal type are presented in Appendix A.

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(10) Keystone Coal Manual, 1973. McGraw-Hill Publications, New York, New York, 1973. pp. 304-410.

(11) Electric Utility Statistics. Public Power, 32:28-84, January-February, 1974.

(12) Steam-Electric Plant Factors/1973 Edition. National Coal Association, Economics and Statistics Division, Washington, D.C., December 1973. 110 pp.

(13) Coke Producers in the United States in 1972. Mineral Industry Surveys, U.S. Department of the Interior, Washington, D.C., 27 November 1973. pp. 2-5.

(14) Minerals Yearbook, 1972, Volume II. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1972. pp. 372.

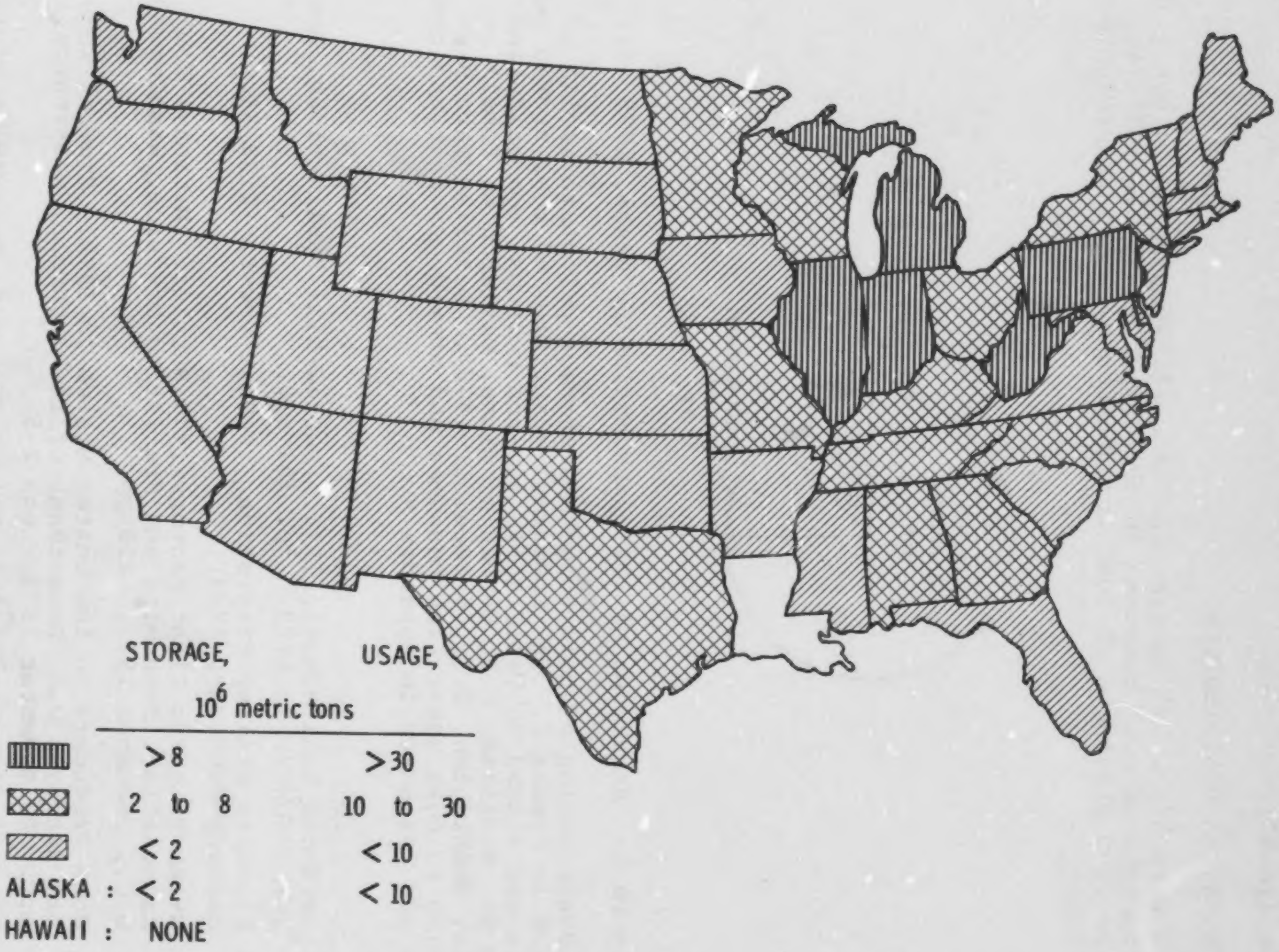
STORAGE,
USAGE,
10⁶ metric tons
▥ >8 >30
▩ 2 to 8 10 to 30
▨ < 2 < 10
ALASKA : < 2 < 10
HAWAII : NONE

Figure 2. Coal usage distribution per state.

TABLE 4. AMOUNT OF COAL STORED PER STATE, 1975 (4, 14)[a]

State	Coal storage, 10^3 metric tons	State	Coal storage, 10^3 metric tons
Alabama	6,098	Nebraska	349
Alaska	113	Nevada	939
Arizona	837	New Hampshire	221
Arkansas	5	New Jersey	333
California	290	New Mexico	1,550
Colorado	1,821	New York	2,216
Connecticut	4	North Carolina	4,384
Delaware	212	North Dakota	1,167
Florida	1,156	Ohio	6,001
Georgia	3,156	Oklahoma	98
Hawaii	None	Oregon	17
Idaho	84	Pennsylvania	14,776
Illinois	10,832	Rhode Island	None
Indiana	9,613	South Carolina	1,140
Iowa	1,372	South Dakota	462
Kansas	699	Tennessee	5,941
Kentucky	10,189	Texas	2,431
Louisiana	None	Utah	686
Maine	5	Vermont	2
Maryland	1,371	Virginia	2,501
Massachusetts	77	Washington	947
Michigan	5,965	West Virginia	11,253
Minnesota	2,177	Wisconsin	2,852
Mississippi	331	Wyoming	1,633
Missouri	4,033	Unaccounted for	1,848
Montana	260		
TOTAL			124,447

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[a] Personal communication with Ms. Williams, Bureau of Mines, Division of Fossil Fuels, Washington, D.C., 6 December 1976.

POTENTIAL POLLUTANTS

Potential pollutants from coal storage piles can be both organic and inorganic in nature. Inorganic material, or mineral matter, is always present in coal and falls into two classes: inherent and extraneous minerals. Inherent minerals are confined within the coal structure. These elements are primarily iron, phosphorus, sulfur, calcium, potassium, and magnesium and comprise generally less than or equal to 2% (by weight) of the coal (1).

Extraneous coal mineral matter is that portion foreign to the plant material that formed the coal structure. These minerals were deposited contemporaneously with the peat (the stage of coal formation prior to lignite), or through cracks after the peat had become consolidated. This portion of the coal is referred to as the ash. The ash content ranges between 3% and 20% (by weight) in coal, with an average of 10%. Ash content is primarily dependent on the care taken in mining and cleaning, and on the quality of the coal itself (1). A general overview of the probable forms of major ash constituents within coal is presented in Table 5 (15).

TABLE 5. MAJOR INORGANIC CONSTITUENTS OF COAL, ASH PORTION (15)

Major inorganic constituent	Forms in coal	
Silicon	Silicates and sand	
Aluminum	Alumina in combination with silica	
Iron	Pyrite and marcasite (sulfide)	
	Ferrous oxide	In small quantities
	Ferrous carbonate	
	Ferrous sulfate	
	Ferric oxide	
	Ferric sulfate	
	"Organic" iron	
	Iron silicates	
Calcium	Lime, carbonate, sulfate, silicates	
Magnesium	Carbonates, silicates	In small quantities
Sodium and potassium	Silicates, carbonates, chlorides	
Manganese	Carbonates, silicates	
Sulfur (inorganic)	Pyrite and marcasite	
	Ferrous sulfate	In small quantities
	Ferric sulfate	
	Calcium sulfate	
Phosphorus	Phosphates	

These elements are primarily rock constituents. The typical range and forms of the major materials in ash per coal rank are shown in Table 6 (16). The quantity of all inorganic elements varies with the specific coal seam and the region in which the coal originated. Therefore the specific geographical sources of the coal stored will affect the concentration of inorganic materials present in the drainage and runoff from the stockpiled coal. In addition to the major inorganic constituents listed in Table 5, a great many trace elements are also found in coal (Table 7). The existence of these materials in coal indicated their possible presence in drainage and runoff from the stockpile.

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(15) Selvig, W. A., and F. H. Gibson. Analysis of Ash from U.S. Coals. Bureau of Mines Bulletin 567, U.S. Department of the Interior, Washington, D.C., 1956. 33 pp.

(16) Mineral Matter and Trace Elements in U.S. Coals. Office of Coal Research R&D Report No. 61, Interim Report No. 2, U.S. Department of the Interior, Washington, D.C., 1972. pp. 63.

TABLE 6. VARIATIONS IN COAL ASH COMPOSITION WITH COAL RANK (16)
(percent of ash)

Rank	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	SO_3
Anthracite	48 to 68	25 to 44	2 to 10	1.0 to 2	0.2 to 4	0.2 to 1			0.1 to 1
Bituminous	7 to 68	4 to 39	2 to 44	0.5 to 4	0.7 to 36	0.1 to 4	0.2 to 3	0.2 to 4	0.1 to 32
Subbituminous	17 to 58	4 to 35	3 to 19	0.6 to 2	2.2 to 52	0.5 to 8			3.0 to 16
Lignite	6 to 40	4 to 26	1 to 34	0.0 to 0.8	12.4 to 52	2.8 to 14	0.2 to 28	0.1 to 1.3	8.3 to 32

Note.—Blanks indicate data not available.

TABLE 7. TRACE INORGANIC ELEMENTS IN COAL (1)

Trace inorganic elements (about 0.1% or less, on ash)
Beryllium
Fluorine
Arsenic
Selenium
Cadmium
Mercury
Lead
Boron
Vanadium
Chromium
Cobalt
Nickel
Copper
Zinc
Gallium
Germanium
Tin
Yttrium
Lanthanum
Uranium
Lithium
Scandium
Manganese
Strontium
Zirconium
Barium
Ytterbium
Bismuth

Information on possible organic pollutants in wastewater from coal storage areas is sparse. Whereas coal by nature is primarily organic, very little information (except for ultimate analysis for percent carbon, hydrogen, oxygen, nitrogen, sulfur, ash, and volatiles) exists on specific compounds within coal. Although no studies were found that measured organic effluents from drainage and subsequent runoff, such effluents are expected to occur because of the organic nature of coal.

In addition to specific inorganic and organic pollutants, other water quality parameters can characterize coal storage wastewaters. Waste coal fragments can erode as solid sediments from a coal pile. Suspended sediments may persist downstream of the site. Adverse impacts on aquatic life and water quality are generated by increases in suspended sediments and acidity. Minerals such as calcium and magnesium can produce undesirable alkalinity and hardness in waters. Ferrous bicarbonate can form, consuming oxygen, creating a bitter taste, and staining materials.

The most widely recognized water pollution problem associated with coal is acid mine drainage. The potential for this same acidity exists for drainage from coal storage; however, the quantity and quality of the pile wastewater are highly variable

(17). Of particular concern are the high concentrations of sulfates which may enter local streams while still reactive.

Acid mine drainage is primarily a mixture of sulfuric acid, iron salts, and aluminum salts. These pollutants result from the oxidation of pyritic materials within the coal. Acid drainage also poses the potential of leaching heavy metals from the coal. This can happen through secondary reactions of sulfuric acid with minerals and organic compounds in the pile and along the runoff route. These reactions may produce concentrations of aluminum, manganese, calcium, sodium, and inorganic elements.

Water pollution from coal storage is widespread because sources are widely distributed, and because iron disulfide minerals (such as pyrite and marcasite) associated with the strata in which coal is found are often retained within the stockpiled coal. Oxidation of iron disulfide initiates the formation of the soluble acidic pollutants. Sulfates from the oxidized pyrite are balanced by an equivalent content of metallic ions (cations) in solution. This indicates that the mineral constituents are salts and that free sulfuric acid is only present in trace amounts. The constituents of concern are 1) sulfates of iron and aluminum in solution as a consequence of pyritic oxidation, 2) solid mineral debris and sediment, and 3) dissolved and colloidal products of geochemical origin. The iron and aluminum sulfates cause low pH values and high acidity values, and may result in corrosiveness, and toxicity to aquatic life.

ENVIRONMENTAL FACTORS

Wastewater from coal stockpiles is generated by drainage and leachate from the coal pile. Pollution is created by the runoff into streams. Drainage refers to the volume of wastewater passing through the coal, including those pollutants leached out of the coal. A variety of environmental factors affect the quality and quantity of emitted pollutants.

Atmospheric Reactions

Stockpiled coal deteriorates from air oxidation, causing a change in chemical composition and heating value. On exposure to the atmosphere, fresh coal reacts with oxygen to form peroxide groups on the pile surface. This is followed by the formation of more stable oxidation compounds and the evolution of oxides of carbon.

The outer layer of a coal pile (to a depth of approximately one-third of a meter) is subject to slacking. Slacking refers to rapid changes in moisture content brought about by alternating sun and rain. This causes fresh surfaces to open up and accelerates the process of oxidation. Oxidation generally decreases the volatile matter and carbon content of the coal. The initial oxidation of coal is rapid, but the rate may fall to one-tenth of the original value after 30 hours (5).

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(17) Anderson, W. C., and M. P. Youngstrom. Coal Pile Leachate Quantity and Quality Characteristics. Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers, 102(EE6):1239-1253, 1976.

Moisture and air in contact with coal also cause oxidation of metal sulfides to sulfuric acid and the precipitation of ferric compounds. Further oxidation can lead to the formation of some simple aromatic acids and oxalic acid (18). When rain falls upon stored coal, the precipitation trickles or seeps down, washing the acid out. The acidic wastes result from contact with the oxidized pyritic materials. These oxidation products are flushed out and diffused by the continuous adsorption of moisture (19).

The first rainfall on freshly stored coal also washes out the accumulated minerals retained within the pile. Chemical pollutants and suspended solids are thus transported in coal pile drainage. Drainage flows from the pile and runs off into waterways and underground streams, creating a potential for contamination.

Drainage

The characteristics of coal pile wastewaters are dependent on the hydrologic, topographic, and geological features of the drainage area. The concentration of pollutants varies as a function of the quantity of water, contact time, and presence of reactive materials.

Discharge of pollutants is intermittent, occurring during and after periods of precipitation. Drainage may run off to waterways, or be trapped in trenches or pits. Trapped pools may contain high concentrations of the pollutants. During subsequent periods of rainfall these pools may run off, releasing concentrated "slugs" of pollution to receiving streams. Aquatic life may be damaged by these doses (20). The configuration of the stockpile, terrain within close proximity to the pile, and pile volume will also affect water volumes discharged.

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(18) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Volume 5. John Wiley & Sons, Inc., New York, New York, 1967. pp. 606-678.

(19) Morth, A. H., E. E. Smith, and K. S. Shumate. Pyritic Systems: A Mathematical Model. EPA-R2-72-002, U.S. Environemntal Protection Agency, Washington, D.C., November 1972. 171 pp.

(20) The Incidence and Formation of Mine Drainage Pollution in Appalachia. Appalachian Regional Commission, Washington, D.C., June 1969. 464 pp.

The quality of the drainage depends upon the above factors; on coal type, quality, and size; and on reaction time (which varies with precipitation conditions).

There are two components of drainage flow from a coal stockpile, base and surface flow. Base flow consists of the groundwater which passes through the bottom layer of the stockpile. This flow is a result of pile site configuration, fluctuations in groundwater levels, and precipitation which infiltrates the pile and later emerges during dry periods. Surface flow is attributed to storm-induced runoff waters from pile drainage (17).

Data inputs required for quantifying runoff from a coal storage source include: drainage basin area, duration of rainfall, amount of rainfall, excess rainfall, infiltration rates, and soil type.

Runoff

Runoff from a drainage basin is a product of the hydrologic cycle which is influenced by climatic and physiographic factors. Climatic factors include the effects of types of precipitation, interception, evaporation, and transpiration, all of which experience seasonal variations. Physiographic factors include size, shape, and slope of drainage area, permeability and capacity of groundwater formations, presence of lakes and swamps, land use, and channel carrying and storage capacities. The relationship between precipitation and runoff is not direct; factors such as storm frequency, initial soil moisture condition, storm duration, and time of year must be determined (21).

The soil moisture condition is the summation of the precipitation amounts occurring prior to a storm, weighted according to the time of occurrence. Storm precipitation is the average over the basin (an arithmetic mean is generally used). The value of storm duration is derived from six 1-hour precipitation readings and the sum of those regions with rainfall greater than 5.1 mm/hr (greater than 0.2 in. rain/hr) plus one-half of those regions with rain less than 5.1 mm/hr (less than 0.2 in. rain/hr). These rainfall runoff parameters can thus provide a basis for establishing an estimate of the volume of water which will run off from the average storm (21). The largest coal storage regions (Figure 2) have an approximated average runoff of 51 cm/yr (20.1 in./yr) (22).

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(21) Handbook of Applied Hydrology. Ven te Chow, ed. McGraw-Hill Book Co., New York, New York, 1964. pp. 14-1 through 14-54.

(22) Geraghty, J. J., D. W. Miller, F. Van der Leeden, and F. Y. Troise. Water Atlas of the United States. Water Information Center, Inc., Port Washington, New York, 1973. Plate 21.

Water runoff from coal stockpiles can range from 64,000 m^3/yr to 320,000 m^3/yr (17 x 10^6 gal/yr to 85 x 10^6 gal/yr) with an average in the range of 75,000 m^3/yr to 100,000 m^3/yr (20 x 10^6 gal/yr to 26 x 10^6 gal/yr) (23).

FACTORS AFFECTING EMISSIONS

Since acid mine drainage (AMD) reactions are believed to be similar to those occurring within stockpiled coal, they are presented below.

As the atmosphere comes in contact with coal during mining, two processes are initiated: 1) the chemical change of oxidation and 2) the physical change of size degradation. As stated earlier, the initial rate of oxidation of freshly exposed coal falls off rapidly with time. This oxidation rate is proportional to the total surface area, which depends upon the particle size or size grading of the coal. Fresh surfaces are created within the pile by rainfall as it removes pyritic oxidation products. The fresh surfaces permit the regeneration of oxidation products until the next rain, at which time they are washed out again.

Ferrous sulfite is formed by pyritic oxidation but is slow to react until oxidized to the ferric state. The acidity produced by pyritic oxidation is highly concentrated and reactive. It reacts with rock minerals, forming aluminum sulfate and other soluble decomposition products (20).

In general, bright coal is more susceptible to oxidation than hard, dull coal, and low rank coal suffers greater degradation in storage than does anthracite. A freshly broken surface is more subject to oxidation, and thus the surface of the coal loses its lustre on storage. The smallest sizes of coal oxidize most readily due to their large surface area (18). Temperature also affects the rate of oxidation. It has been shown that the oxidation rate may double for every 10°C to 20°C rise.

Chemical changes take place both in the mineral impurities present and in the coal substance itself. The changes in minerals become evident by the rusty appearance that results from interaction by oxidation products from the pyrites with any carbonate present (24). Factors that affect the rate of pyrite oxidation are oxygen concentration, particle size, temperature, moisture, pH, and electrode potential of the reaction (25). The crystal size and form of the pyrite also contribute greatly to the rapid oxidation. The rate of pyrite oxidation, however, is not dependent upon the amount of water present. Pyrite oxidation is for all purposes continuous, while drainage flow is variable throughout the year. There is also a strong possibility that various bacteria catalyze the oxidation of pyrites. The actual mechanism by which bacteria enter into the oxidation of pyrite has not been definitely established (26).

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(23) Development Document for Proposed Effluent Limitation Guidelines and New Source Performance Standards for the Steam Electric Power Generating Point Source Category. EPA-440/1-73-029, U.S. Environmental Protection Agency, Washington, D.C., March 1974. pp. 128-130.

(24) Hall, D. A. The Storage of Coal. Coke and Gas, December 1956. pp. 498-504.

Storm runoff from AMD has detrimental effects on aquatic life when solute concentrations are suddenly increased. Concentrations of solutes are generally highest in the first flush after dry periods. This occurs after unusually heavy thunderstorms which produce "slugs" of pollution, primarily in the summer. Decreased flow in the summer and fall also increases pollutant concentration. Detrimental effects generally occur less frequently in the winter. Although more dissolved constituents are produced during the winter and early spring, water quality and aquatic life are less affected then due to the higher stream flows and lower water temperatures which reduce the pollutant concentrations. These factors also retard the oxidation of ferrous ions and hydrolysis of ferric and aluminum sulfate (20). A bench-scale study of parameters that alter the biological and chemical effects of coal storage runoff on water quality is being conducted under EPA Grant No. NERC-R-803937-01-0 by the Center for Lake Superior Environmental Studies.[a]

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[a] Nathan A. Coward, Department of Chemistry, University of Wisconsin at Superior, Wisconsin.

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(25) Lorenz, W. C., and R. W. Stephan. The Oxidation of Pyrite Associated with Coal Mines. U.S. Department of the Interior, Bureau of Mines, Pittsburgh, Pennsylvania, 1967. 21 pp.

(26) Lorenz, W. C., and R. W. Stephan. Factors that Affect the Formation of Coal Mine Drainage Pollution in Appalachia. U.S. Department of the Interior, Bureau of Mines, Pittsburgh, Pennsylvania, 1967. 17 pp.

SECTION 4

WATER DISCHARGES

DATA COMPILATION

Scope

As described in Section 3, wastewater from a coal storage source can vary with a large number of factors. However, quantifying the effect of these variables on effluent levels is beyond the scope of this project. Instead, data on major effluent parameters are aggregated to define average wastewater levels from all sources. Since the purpose of examining wastewaters is to establish the exposure of life forms to pollutants from the source, the pollutant selected for study were those with known effects on life.

Coal is composed of a vast quantity of known and unknown elements and compounds (Tables 5-7). This study, however, is limited to those effluents 1) defined as hazardous, and/or 2) regulated by effluent limitations. Other water quality parameters are investigated to indicate the possible presence of specific materials and to determine the degree of further analysis required.

Hazardous elements are those materials specified by the toxic substances law and listed in Table 8 (27). Pesticides on the list are excluded from this study since their presence in coal drainage and runoff is unlikely and has not been detected during sampling. The parameters of pH and total suspended solids (TSS) and the elements Fe and Mn are included in this study since they appear in effluent limitations for coal storage areas. The total organic carbon (TOC) content of effluents is investigated to establish the need for analysis of the organics in Table 8. Total chloride levels are included to indicate the possible presence of carcinogenic organochlorine compounds, especially in tandem with high TOC results. Nitrate and total phosphorus levels are determined to measure nutrients, and therein the possible degree of algae formation. The degree of dissolved oxygen depletion and the subsequent danger to aquatic life are established by the levels of 5-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD).

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(27) Sampling and Analysis Procedures for Survey of Industrial Effluents for Priority Pollutants. U.S. Environmental Protection Agency, Cincinnati, Ohio, March 1977. 180 pp.

TABLE 8. HAZARDOUS SUBSTANCES LIST (27)

Compound name
Acenaphthene
Acrolein
Acrylonitrile
Benzene
Benzidine
Carbon tetrachloride (tetrachloromethane)
Chlorinated benzenes (other than dichlorobenzenes):
Chlorobenzene
1,2,4-Trichlorobenzene
Hexachlorobenzene
Chlorinated ethanes (including 1,2-dichloroethane, 1,1,1-trichloroethane and hexachloroethane):
1,2-Dichloroethane
1,1,1-Trichloroethane
Hexachloroethane
1,1-Dichloroethane
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
Chloroethane
Chloroalkyl ethers (chloromethyl, chlorethyl and mixed ethers):
Bis(chloromethyl) ether
Bis(2-chlorethyl) ether
2-Chloroethyl vinyl ether (mixed)
Chlorinated naphthalene:
2-Chloronaphthalene
Chlorinated phenols (other than those listed elsewhere; includes trichlorophenols and chlorinated cresols):
2,4,6-Trichlorophenol
p-chloro-*m*-cresol
Chloroform (trichloromethane)
2-Chlorophenol
Dichlorobenzenes:
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene

(continued)

TABLE 8 (continued)

Compound name
Dichlorobenzidine:
3,3'-Dichlorobenzidine
Dichloroethylenes (1,1-dichloroethylene and 1,2-dichloroethylene):
1,1-Dichloroethylene
1,2-*Trans*-dichloroethylene
2,4-Dichlorophenol
Dichloropropane and dichloropropene:
1,2-Dichloropropane
1,3-Dichloropropylene (1,3-dichloropropene)
2,4-Dimethylphenol
Dinitrotoluene:
2,4-Dinitrotoluene
2,6-Dinitrotoluene
1,2-Diphenylhydrazine
Ethylbenzene
Fluoranthene
Haloethers (other than those listed elsewhere):
4-Chlorophenyl phenyl ether
4-Bromophenyl phenyl ether
Bis(2-chloroisopropyl) ether
Bis(2-chloroethoxy) methane
Halomethanes (other than those listed elsewhere):
Methylene chloride (dichloromethane)
Methyl chloride (chloromethane)
Methyl bromide (bormomethane)
Bromoform (tribromomethane)
Dichlorobromemethane
Trichlorofluoromethane
Dichlorodifluoromethane
Chlorodibromomethane
Hexachlorobutadiene
Hexachlorocyclopentadiene

(continued)

TABLE 8 (continued)

Compound name
Isophorone
Naphthalene
Nitrobenzene
Nitrophenols (including 2,4-dinitrophenol and dinitrocresol):
2-Nitrophenol
4-Nitrophenol
2,4-Dinitrophenol
4,6-Dinitro-*o*-cresol
Nitrosamines:
N-nitrosodimethylamine
N-nitrosodiphenylamine
N-nitroso-di-n-propylamine
Pentachlorophenol
Phenol
Phthalate ethers:
Bis(2-ethylhexyl) phthalate
Butyl benzyl phthalate
Di-n-butyl phthalate
Diethyl phthalate
Dimethyl phthalate
Polynuclear aromatic hydrocarbons:
Benz(a)anthracene (1,2-benzathracene)
Benzo(a)pyrene (3,4-benzopyrene)
3,4-Benzofluoranthene
Benzo(k)fluoranthene (11,12-benzofluoranthene)
Chrysene
Acenaphthylene
Anthracene
Benzo(ghi)perylene (1,12-benzoperylene)
Fluorene
Phenanthrene
Dibenz(a,h)anthracene (1,2:5,6-dibenzanthracene)
Indeno(1,2,3-c,d)pyrene (2,3-*o*-phenylenepyrene)
Pyrene
Tetrachloroethylene

(continued)

TABLE 8 (continued)

Compound name
Toluene
Trichloroethylene
Vinyl chloride (chloroethylene)
Pesticides and metabolites:
Aldrin
Dieldrin
Chlordane (technical mixture and metabolites)
DDT and metabolites:
4,4'-DDT
4,4'-DDE (p,p'-DDX)
4,4'-DDD (p,p'-TDE)
Endosulfan and metabolites:
α-Endosulfan
β-Endosulfan
Endosulfan sulfate
Endrin and metabolites:
Endrin
Endrin aldehyde
Heptachlor and metabolites:
Heptachlor
Heptachlor epoxide
Hexachlorocyclohexane:
α-BHC
β-BHC
γ-BHC (lindane)
δ-BHC
Polychlorinated biphenyls (PCB's):
PCB-1242 (Arochlor 1242)
PCB-1254 (Arochlor 1254)
PCB-1221 (Arochlor 1221)
PCB-1232 (Arochlor 1232)
PCB-1248 (Arochlor 1248)
PCB-1260 (Arochlor 1260)
PCB-1016 (Arochlor 1016)

(continued)

TABLE 8 (continued)

Compound name
Toxaphene
Elements:
Antimony (Total)
Arsenic (Total)
Asbestos (Fibrous)
Beryllium (Total)
Cadmium (Total)
Chromium (Total)
Copper (Total)
Cyanide (Total)
Lead (Total)
Mercury (Total)
Nickel (Total)
Selenium (Total)
Silver (Total)
Thallium (Total)
Zinc (Total)
2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD)

Sulfate concentrations are included since they indicate the acid-forming potential of the wastestream.

Asbestos measurements would have required a large volume of filterable sample and would not have been practicable with the approach used in this study. Therefore an analysis for free silica was performed as an indication of the presence of asbestos.

Approach

To assess effluents from coal storage areas the EPA Procedures Manual (28) recommends direct field sampling methods. In this instance that would have entailed: 1) sampling at a number of different locations throughout the country, 2) setting up each sampler so as to avoid interference from bulldozers that operate around the pile, 3) awaiting sufficient rainfall, 4) maintaining the samplers within the wastewater drainage, 5) measuring specific parameters immediately after the rainfall, and 6) preserving and transporting the samples for analysis by standard methods (29). This would have involved excessive amounts of both the time and money allotted to the project. Laboratory simulation of rainfall and drainage from coal piles was thus undertaken as a feasible alternative.

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(28) Hamersma, J. W., S. L. Reynolds, and R. F. Maddalone. IERL-RTP Procedures Manual: Level 1 Environmental Assessment. EPA-600/2-76-160a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1976. pp. 60-64.

A rainfall simulator was utilized to obtain the minute drop size (less than 5 μm) and low rainfall rates (less than or equal to 50 mm/hr) necessary. These factors allowed complete and uniform coverage of coal placed under the simulator. The simulator also permitted an adequate water-coal pile contact time and allowed the trickling of water through the pile that occurs during actual rainfalls.

Figure 3 shows the simulator as it was utilized in this study. The coal samples, each weighing 9.1 kg (20 lb), were placed in pans beneath the rainfall modules. The modules were enclosed plastic containers fed distilled water from a centrifugal pump. Water flow was controlled by electric valves in line with each of four pipes connected to each module. Drains were placed within the bottom of each pan. The drainage was then collected in bottles and analyzed for the parameters discussed previously. Further details of the simulation and sampling arrangements are presented in Appendix B.

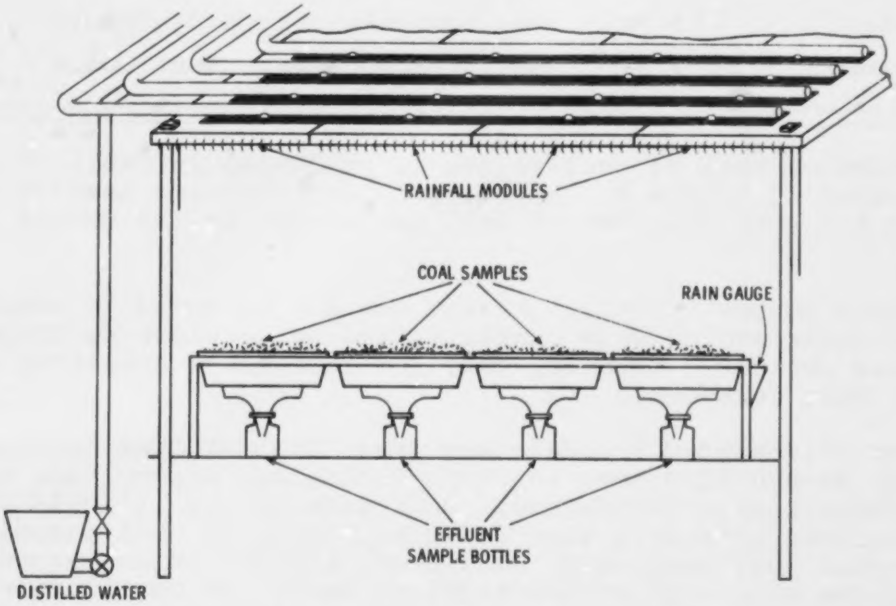

Figure 3. Rainfall simulation apparatus.

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(29) Standard Methods for the Examination of Water and Wastewater, 14th Edition. M. A. Franson, ed. American Public Health Association, Washington, D.C., 1976. 1193 pp.

REPRESENTATIVE SOURCE

Coal Composition

The coal producing areas of the United States are grouped into the six regions listed in Table 9, which also identifies the states included in each region.

TABLE 9. COAL REGIONS OF THE UNITED STATES (1)

Region	Abbreviation	States included
Appalachian	A	Pennsylvania, Ohio, West Virginia, Maryland, Virginia, Eastern Kentucky, Tennessee, Alabama, Georgia
Interior-Eastern	IE	Illinois, Indiana, Western Kentucky, Michigan
Interior-Western	IW	Iowa, Missouri, Nebraska, Kansas, Oklahoma, Arkansas, Texas
Western	W	Wyoming, Idaho, Utah, Colorado, New Mexico, Arizona, Washington
Southwestern	SW	Utah, Colorado, Arizona, New Mexico
Great Northern Plains	NP	Montana, North Dakota, South Dakota

Production of coal by coal region is presented in Table 10 and illustrated in Figure 4. Appalachian and Interior Eastern coals account for more than 80% of coal production in the United States.

Since data on the specific organic content of coals is sparse, average coals stored were characterized by considering their inorganic content. However, only the inorganics appearing in Table 8 were considered.

The composition of U.S. coals was drawn from studies performed by the U.S. Bureau of Mines, the U.S. Geological Survey, and the U.S. Atomic Energy Commission. Some data by the Illinois State Geolcgical Service were also included. Data on coal composition represented coal samples as delivered, cleaned or uncleaned, or coal in the mine with no distinctions made. No correlations between trace element content and coal location were performed.

The average concentrations of the inorganics (Table 8) in coal throughout the coal regions (Table 9) of the United States are presented in Table 11. The national average inorganic element content of coals was determined by weighting these averages by the production per coal region (Table 10). These weighted values

TABLE 10. COAL PRODUCTION BY COAL REGION (4)

Region/State	U.S. Bureau of Mines District	Coal production	
		10^6 metric tons	10^6 tons
Appalachian:			
Western Pennsylvania	2	36	40
Eastern Pennsylvania, Maryland, and West Virginia	1	48	53
Ohio	4	42	46
West Virginia	3 and 6	38	42
North Carolina, Eastern Kentucky, Tennessee, West Virginia, and Virginia	8	145	160
Virginia and West Virginia	7	26	29
Tennessee, Alabama, and Georgia	13	21	23
TOTALS		356	393
Interior Eastern:			
Illinois	10	55	61
Indiana	11	23	25
Western Kentucky	9	51	56
TOTALS		129	142
Interior Western:			
Iowa	12	0.6	0.7
Missouri, Oklahoma, Texas, and Kansas	15	18	20
Arkansas and Oklahoma	14	0.9	1.0
TOTALS		19.5	21.7
Western:			
Northern Colorado	16	0.4	0.44
Wyoming and Idaho	19	22	24
Utah[a]	20	3	3.3
Oregon, Alaska, and Washington	23[a]	12	13
New Mexico, Arizona, and California	18	14	15
TOTALS		51.4	55.7
Southwestern:			
Utah[a]	20	3	3.3
Colorado and New Mexico	17	8	8.8
New Mexico, Arizona, and California	18	14	15
TOTALS		25	27.1
Great Northern Plains:			
Montana[a]	22	12	13
South Dakota and North Dakota	21	8	8.8
TOTALS		20	21.8

[a] Production estimated by dividing production in districts equally between footnoted states.

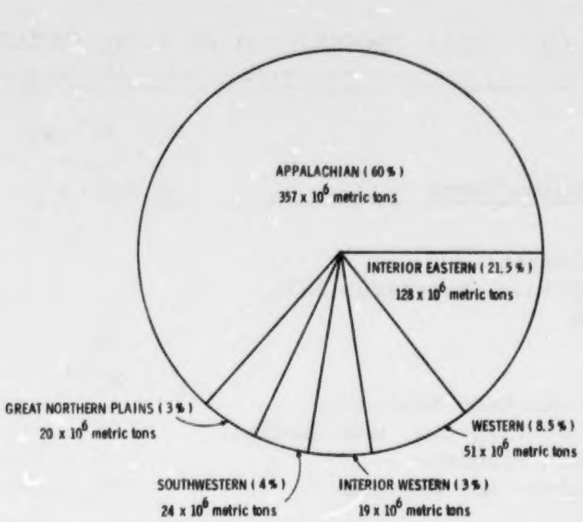

Figure 4. Production of coal by coal region (4).

TABLE 11. AVERAGE CONTENT (PERCENT) OF HAZARDOUS INORGANIC ELEMENTS WITHIN COALS (1)

	Coal region					
Inorganic element	Appalachian	Interior Eastern	Interior Western	Great Northern Plains	Southwestern	Western
Antimony	0.001[a]	N.A.[b]	N.A.	N.A.	N.A.	N.A.
Arsenic	0.0031[c]	0.0011[d]	N.A.	0.08[c]	0.0073[e]	0.0004[a]
Asbestos	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Beryllium	0.0025[e]	0.0025[e]	0.0015[c]	0.0015[e]	0.00006[a]	0.0015[e]
Cadmium	N.A.	N.A.	N.A.	N.A.	0.000003[c]	N.A.
Chromium	0.0013[d]	0.002[e]	0.0014[c]	0.0007[e]	0.006[a]	0.00069[d]
Copper	0.0015[d]	0.0011[e]	0.0012[c]	0.0015[e]	0.0008[c]	0.00046[d]
Cyanides	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Lead	0.0009[c]	0.0011[c]	0.0004[e]	0.0007[e]	0.0006[d]	0.0008[c]
Mercury	0.000015[e]	0.000013[e]	0.000019[e]	0.000007[e]	0.000013[c]	0.000007[e]
Nickel	0.0014[e]	0.0015[e]	0.0017[a]	0.00072[e]	0.0006[d]	0.00053[d]
Sulfur	0.00018[e]	0.00034[e]	0.00029[e]	0.00007[e]	N.A.	0.00008[e]
Thallium	0.00018[d]	0.00007[d]	N.A.	N.A.	N.A.	0.00005[d]
Silver	0.00008[d]	N.A.	N.A.	N.A.	N.A.	N.A.
Zinc	0.00082[c]	0.0044[e]	0.0193[d]	0.0059[a]	0.0009[d]	0.0025[d]

[a] Product of average of the range of element percentages in ash and average ash content of coal.

[b] Not available.

[c] Based on average of the ranges of percent of the element in coal.

[d] Product of average value of ash content of element in coal and average ash content of coal.

[e] Based on average percent of element in coal as reported.

were used to establish those coal regions that best represent inorganic element content. The national production-weighted averages per inorganic element are presented in Table 12. Those coal regions whose average element contents (Table 10) best approximate the national average are also listed in Table 12. Every region, except the Great Northern Plains, contains element contents that approximate the national production-weighted average concentration. Coals from all coal regions were therefore studied in characterizing effluent levels from stockpiles. Great Northern Plains coals were included since these coals account for a large percent of the U.S. coal reserves and future consumption and storage quantities (Section 6).

Within each coal region, a variance ratio was available for numerous elements. This is the ratio of the highest to lowest to which selection of a coal within a coal region will affect concentration of an inorganic element in coal. The variance ratio was within 2 to 3 for 53% of the elements studied with only one element (germanium) above 10 (1). This illustrates that the selection of a coal within a particular coal region will not affect the inorganic element content by more than one order of magnitude for the average of analyses. This justifies a random selection of coal within each coal region to represent the average inorganic element content (Tables 11 and 12).

The selection of coal from a coal region is accomplished on a state basis. Because the Appalachian region accounts for approximately 60% of total U.S. coal production, two states from that region were chosen for study to provide a better cross section of effluent levels. Alabama and Eastern Kentucky coals were chosen since Alabama coal is close to lignite coals, and Eastern Kentucky coal is subbituminous, as is most Appalachian coal. For the Interior Eastern, Interior Western, Great Northern Plains, Southwestern, and Western coal regions, coals from Illinois, Missouri, Montana, New Mexico, and Wyoming, respectively, were studied since these states account for the highest coal production in those regions (Table 10).

Stockpile Parameters

The distribution of coal stockpile sizes is shown in Figure 5. The arithmetic mean stockpile size is 95,000 metric tons (105,000 tons) with a modal value of 49,000 metric tons (52,000 tons) (6). The arithmetic mean value is used to represent effluent levels from all coal stockpiles.

The surface area (Sp) of the representative coal stockpile is computed from Equation 2.

$$Sp = \frac{X}{\rho B \cdot H} \qquad (1)$$

TABLE 12. PRODUCTION-WEIGHTED INORGANIC ELEMENT CONTENT OF COALS

Element	National production-weighted average, percent in coal	Representative regions
Antimony	0.001	Appalachian
Arsenic	0.005	Appalachian
Asbestos	N.A.[a]	N.A.
Beryllium	0.002	Appalachian and Interior Eastern
Cadmium	0.000003	Southwestern
Chromium	0.0015	Interior Western
Copper	0.0013	Interior Western
Cyanides	N.A.	N.A.
Lead	0.00089	Appalachian
Mercury	0.000013	Interior Eastern
Nickel	0.0013	Appalachian
Sulfur	0.0002	Interior Western
Thallium	0.00014	Appalachian
Silver	0.00008	Appalachian
Zinc	0.0025	Western

[a] Not available.

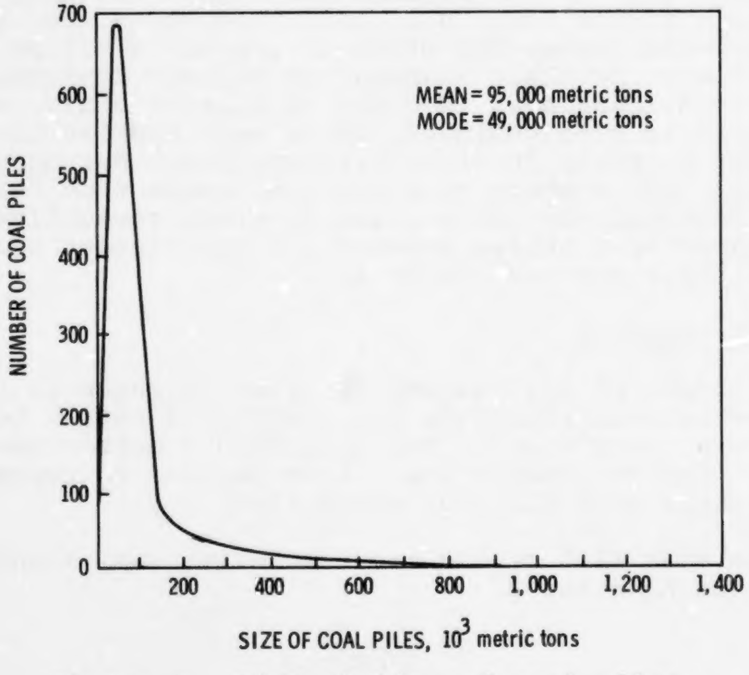

Figure 5. Distribution of coal piles.

where Sp = surface area, cm^2
X = amount of coal stored, g
ρB = bulk density, g/cm^3
H = pile height, cm

The height of coal stockpiled, H, is generally 4.3 m to 8.8 m (14 ft to 29 ft), with an average of about 5.8 m (19 ft) (30). A random survey of 12 coal storage sites (Table 13) indicated a range of 2.4 m to 11.3 m (8 ft to 37 ft) in height, with an average of 6 m (19.6 ft). This value is within 3% of the reported data. The surface area of the representative coal stockpile, Sp, is calculated from Equation 2 to be 19,792 m^2 (212,961 ft^2).

TABLE 13. SURVEY OF DISTRIBUTION OF DISTANCES TO PLANT BOUNDARY AND POPULATION DENSITY FOR COAL STOCKPILE LOCATIONS (6)

	Coal pile size		Distance to boundary		Population density	
Site	10^3 metric tons	10^3 tons	m	ft	persons/ km^2	persons/ $mile^2$
1	2.7	3	134	440	20	52
2	66	73	46	150	409	1,060
3	58	64	61	200	24	63
4	38	42	15	50	22	58
5	418	461	152	500	1	3
6	254	280	91	300	0.4	1
7	10	11	15	50	4	10
8	45	50	244	800	26	68
9	530	584	792	2,600	161	417
10	41	45	46	150	16	42
11	3.6	4	30	10	30	78
12	2.7	3	53	175	2	4
Mean (biased)	122	135	88	288	60	155
Standard deviation	179	198	72	236	118	306
Mean	122	134	86	282	61	158

The error in computing the representative storage quantity, X, varies with the type of user facility for the three prime users the standard deviations listed in Table 14 occur.

The overall weighted variation due to normal storage fluctuations is ±61%.

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(30) Annual Report of Research and Technologic Work on Coal. IC 7518, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1949. 39 pp.

TABLE 14. DEVIATIONS OF COAL STOCKPILE INVENTORIES, PER USER (6)

User	Days of supply	Standard deviation
Coke plants	23	±43%
Boiler plants	39	±59%
Utilities	93	±74%

The overall weighted variation due to normal storage fluctuations is ±61%.

A coal density, ρB, of 800 kg/m^3 (50 lb/ft^3) introduces a variation of ±10%. A pile height of 5.8 m (19 ft) has a variation of ±26%. The overall uncertainty of the surface area computed from Equation 2 will thus be ±97%.

From Table 13, the survey also indicated that the average distance to the boundary from the coal pile is 86 m (282 ft) (6).

Runoff Levels

Runoff is that part of precipitation and other flow contributions which appears in waterways perennially or intermittently. It is flow collected from a drainage basin or watershed as it appears at the outlet of the basin. The land surrounding a coal stockpile is considered the drainage basin in this study. It is runoff from this area that receives leachate and drainage materials from a coal stockpile. The outlet of this basin is the runoff level as it appears at the receiving waterway for the representative source.

Establishing the pollutant concentrations to which lifeforms are exposed in these waterways from the representative source, requires a knowledge of these runoff flows. There are three types of runoff: surface, subsurface, and groundwater.

Surface runoff travels over the ground surface and through channels to reach the basin outlet. Subsurface runoff is a result of precipitation that infiltrates the surface soil and moves laterally through the upper horizons toward the streams as groundwater above the main groundwater level. Groundwater flow is caused by deep percolation of the infiltrated water which has passed into the ground and has become groundwater. After the flow enters a stream, it joins with other components of flow to become total runoff (21).

Total runoff is classified as direct runoff and base flow. Direct runoff enters the stream promptly after precipitation. Base flow is the fair weather runoff. From precipitation to runoff, the various flows are related as shown in Figure 6.

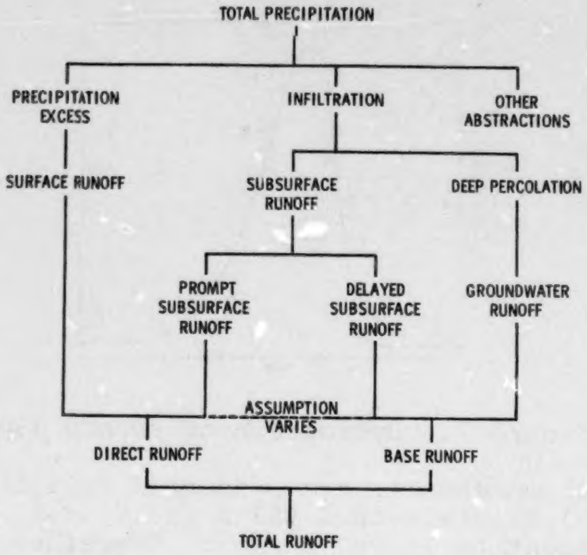
TOTAL PRECIPITATION
PRECIPITATION EXCESS
INFILTRATION
OTHER ABSTRACTIONS
SURFACE RUNOFF
SUBSURFACE RUNOFF
DEEP PERCOLATION
PROMPT SUBSURFACE RUNOFF
DELAYED SUBSURFACE RUNOFF
GROUNDWATER RUNOFF
ASSUMPTION VARIES
DIRECT RUNOFF
BASE RUNOFF
TOTAL RUNOFF

Figure 6. Hydrological overview of runoff (21).

Total runoff discharges to streams vary as a function of time. This relationship is best illustrated through a typical hydrograph as shown in Figure 7 (31). In this figure, the segment A-B reflects the time lag between commencement of rainfall and beginning of runoff. Segment B-D represents the runoff to the peak at point D. The recession flow, segment D-F, reflects the decreased runoff after rain has ceased. The shape of the hydrograph depends upon rainfall quantities, duration, and intensity, and upon the character of the soil of the drainage basin area. The area and topography of the drainage basin determine the amount of liquid discharged to the nearest waterway.

In addition, runoff will vary over long periods of time with the following factors: 1) rainless periods, 2) initial period of rain, 3) continuation of rain at variable intensity, 4) continuation of rain until natural storage has been satisfied, and 5) length of time between termination of rain and a return to a rainless period. Consideration of an entire year's rainfall over an area will provide an overview of all these periods.

Runoff levels from the representative coal storage area are determined by considering the annual arithmetic mean rainfall and snow levels. These levels, computed in a coal storage per state

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(31) Method for Identifying and Evaluating the Nature and Extent of Non-Point Sources of Pollutants. EPA-430/9-73-014, U.S. Environmental Protection Agency, Washington, D.C., October 1973. 261 pp.

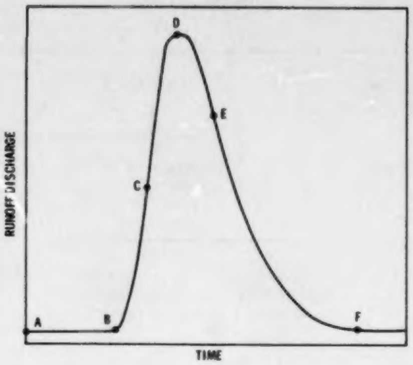

Figure 7. Hydrograph of runoff (31).

(Table 3) weighted manner, are presented in Table 15 (32). The weighted annual rainfall is 0.957 m (37.7 in.). A centimeter of rain is equivalent to 10,000 m^3/km^2. Therefore, 0.957 m (37.7 in.) of rain per year represents 957,000 m^3/km^2-yr (87.5 x 10^6 ft^3/mi^2-yr). The number of days of rain (greater than or equal to 1 mm, or greater than or equal to 4 x 10^2-in.) in the United States is computed in Table 16 (32) as a coal storage weighted national average of 139 days. Therefore the average of 957 x 10^3 m^3/km^2-139 days (87.5 x 10^6 ft^3/mi^2-139 days), 6,885 m^3 (243,000 ft^3) of rain fall per square kilometer per day, is equivalent to a representative rainfall of 0.7 cm (0.3 in.) per day. The average rainfall duration is found by investigating a region where the annual rainfall approximates the representative 95.7 cm/yr (37.7 in./yr). In this region rain falls at 0.6^3 cm/hr (0.25 in./hr) 50% of the time, and 1.27 cm/hr (0.5 in./hr) 40% of the time (personal communication with Dr. Lawrence Huggins, Purdue University, Department of Agricultural Engineering, 7 January 1977). The representative rainfall of 0.7 cm/day (0.27 in./day) therefore occurs in a 1-hr period. The rainfall intensity for the representative coal storage source is 0.7 cm/hr (0.27 in./hr). The area that receives effluents from a coal storage source includes the pile surface area of 19,792 m^2 (212,961 ft^2), and the surrounding area subject to runoff.

Determination of total runoff quantities can be accomplished through use of an empirical method known as the "Rational Method". Runoff is related to rainfall intensity by Equation 3 (33):

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(32) The World Almanac and Book of Facts, 1976. G. E. Delury, ed. Newspaper Enterprise Association, New York, New York, 1975. 782 pp.

(33) Handbook of Water Resources and Pollution Control. H. W. Gehm and J. I. Bregman, eds. Van Nostrand Reinhold Co., New York, New York, 1976. pp. 444-447.

TABLE 15. ANNUAL AND WEIGHTED ANNUAL PRECIPITATION LEVELS PER STATE (32)

	Normal annual precipitation		Coal storage weighted rainfall	
State	m	in.	cm	in.
Alabama	1.496	58.9	7.4	2.9
Alaska	1.389	54.7	0.1	0.04
Arizona	0.179	7	0.1	0.04
Arkansas	1.232	48.5	<0.1	<0.04
California	0.426	16.8	0.1	0.04
Colorado	0.394	15.5	0.6	0.23
Connecticut	1.169	46	<0.1	<0.04
Delaware	1.022	40.2	0.2	0.08
Florida	1.451	57.1	1.4	0.55
Georgia	1.228	48.3	3.1	1.2
Hawaii	0.582	22.9	None	None
Idaho	0.292	11.5	<0.1	<0.04
Illinois	0.875	34.4	7.7	3.0
Indiana	0.984	38.7	7.7	3.0
Iowa	0.845	33.3	0.9	0.4
Kansas	0.722	28.4	0.4	0.16
Kentucky	1.095	43.1	9.1	3.6
Louisiana	1.442	56.8	None	None
Maine	1.036	40.8	<0.1	<0.04
Maryland	1.028	40.5	1.1	0.4
Massachusetts	1.080	42.5	0.1	0.04
Michigan	0.796	31.3	3.9	1.5
Minnesota	0.659	25.9	1.2	0.5
Mississippi	1.257	49.5	0.3	0.12
Missouri	0.912	35.9	3.0	1.2
Montana	0.289	11.4	0.1	0.04
Nebraska	0.767	30.2	0.2	0.08
Nevada	0.219	8.6	0.2	0.08
New Hampshire	0.919	36.2	0.2	0.08
New Jersey	1.076	42.4	0.3	0.12
New Mexico	0.246	9.7	0.3	0.12
New York	0.952	37.5	1.7	0.67
North Carolina	1.091	42.9	3.9	1.5
North Dakota	0.410	16.1	0.4	0.16
Ohio	0.953	37.5	4.7	1.8
Oklahoma	0.797	31.4	0.1	0.04
Oregon	0.955	37.6	<0.1	<0.04
Pennsylvania	0.985	38.8	11.9	4.7
Rhode Island	1.027	40.4	None	None
South Carolina	1.324	52.1	1.2	0.5
South Dakota	0.464	18.3	0.2	0.08
Tennessee	1.168	46	5.7	2.2
Texas	0.932	36.7	1.9	0.75

(continued)

TABLE 15 (continued)

State	Normal annual precipitation m	in.	Coal storage weighted rainfall cm	in.
Utah	0.385	15.2	0.2	0.08
Vermont	0.827	32.6	<0.1	<0.04
Virginia	1.135	44.7	2.3	0.9
Washington	0.714	28.1	0.6	0.2
West Virginia	0.976	38.4	9.0	3.5
Wisconsin	0.752	29.6	1.8	0.7
Wyoming	0.383	15.1	0.5	0.2
		AVERAGE	95.7	37.7

TABLE 16. DAYS OF PRECIPITATION PER STATE (32).

State	Number of days rain >0.1 cm (>0.04 in.) snow >2.5 cm (>1.0 in.)	Weighted rainfall days
Alabama	124	6.2
Alaska	139	0.1
Arizona	38	0.3
Arkansas	121	<0.1
California	40	0.1
Colorado	105	1.6
Connecticut	unknown	<0.1
Delaware	116	0.2
Florida	107	1.0
Georgia	120	3.1
Hawaii	118	None
Idaho	93	0.1
Illinois	151	13.3
Indiana	150	11.8
Iowa	122	1.4
Kansas	75	0.4
Kentucky	141	11.7
Louisiana	115	None
Maine	153	<0.1
Maryland	124	1.4
Massachusetts	143	0.1
Michigan	184	9.0
Minnesota	140	2.5
Mississippi	116	0.3
Missouri	117	3.8
Montana	83	0.2

(continued)

TABLE 16 (continued)

State	Number of days rain >0.1 cm (>0.04 in.) snow >2.5 cm (>1.0 in.)	Weighted rainfall days
Nebraska	108	0.3
Nevada	55	0.4
New Hampshire	147	0.3
New Jersey	120	0.3
New Mexico	77	1.0
New York	179	3.2
North Carolina	127	4.5
North Dakota	100	1.0
Ohio	168	8.2
Oklahoma	74	0.1
Oregon	150	<0.1
Pennsylvania	145	17.5
Rhode Island	142	None
South Carolina	114	1.1
South Dakota	85	0.3
Tennessee	138	6.7
Texas	95	1.9
Utah	83	0.5
Vermont	208	<0.1
Virginia	113	2.3
Washington	139	1.1
West Virginia	166	15.2
Wisconsin	154	3.6
Wyoming	90	1.2
	Weighted	139.3

$$\overline{Qr} = C \cdot \overline{iR} \cdot Ad \qquad (3)$$

where C = coefficient of runoff
$\overline{iR}$ = average rainfall intensity, m/hr
Ad = area of drainage basin minus pile area, m^2
$\overline{Qr}$ = average rate of runoff, m^3/hr

The surfaces on which rain falls will govern the amount which runs off and the rapidity of its travel across such surfaces. The average coefficient of runoff, C, accounts for this factor. The selection of this coefficient is the most uncertain element in using the rational method. The nature and extent of the surface, and the form and timing of the rainfall, are important considerations also. If the average storm is preceded by other precipitation, absorption and percolation are reduced and areas of surface retention are filled. Therefore, the proportion of runoff will be greater than the conventional coefficient values. In addition, the longer the storm lasts, the fewer the ground losses, and surface saturation and percolation are reduced.

The coefficient of runoff for the coal stockpile area of 19,792 m^2 (213,000 ft^2) is assumed equal to the average coefficient for flat, heavy lawns, C equals 0.15 (33). At the representative rainfall of 0.007 m/hr (0.27 in./hr), the runoff from the pile area is computed as:

$$\overline{Qr} = (19{,}792\ m^2)(0.15)\frac{(0.007\ m)}{hr} \qquad (4)$$

$$\overline{Qr} = 21\ m^3/hr\ (\text{or } 742\ ft^3/hr)$$

The average runoff from an entire coal stockpile area is within the range of 75,000 m^3/yr to 100,000 m^3/yr (2.6 to 3.5 x 10^6 ft^3/yr. Using the average value of 87,500 m^3/yr (3.1 x 10^6 ft^3/yr) minus the pile area runoff (139 hr/yr x 21 m^3/hr = 2,919 m^3/hr) yields a runoff level of 84,581 m^3/yr (3,000 ft^3/yr) attributed to the area surrounding the stockpile.

For light-to-heavy industrial occupancy surrounding a coal storage area, a median coefficient of runoff of 0.7 is used. The runoff rate for this area is obtained by dividing the representative runoff (84,581 m^3/yr), by 139 days per year and one hour per day, to obtain 608 m^3/hr or 0.17 m^3/s (6.1 ft^3/s), Vr. The total rainfall volume rate per hour is thus the pile level, 21 m^3/hr, plus the area level, 608 m^3/hr, or 629 m^3/hr (22,210 ft^3/hr).

The area of the drainage basin is found using Equation 3 at the representative rainfall intensity, iR, of 0.7 cm/hr (0.27 in./hr), coefficient of runoff of 0.7 (average for industrial areas), and area runoff of 0.17 m^3/s (6.1 ft^3/s):

$$Ad = 0.17\ m^3/s\ (3{,}600\ s/hr) \div (0.7)(0.007\ m/hr)$$

$$Ad = 124{,}898\ m^2\ (\text{or } 1.3 \times 10^6\ ft^2)$$

where Ad = area of drainage basin minus pile area

The total area of the basin is thus the pile area of 19,792 m^2 (213 x 10^3 ft^2) plus 124,898 m^2 (1.3 x 10^6 ft^2), or 144,690 m^2 (1.6 x 10^6 ft^2).

Runoff levels vary with the topographic features of the area. However, it is assumed that the stockpile and its surrounding area are flat since this would ease the storing, transporting, and handling of the coal aggregate. Therefore, only the areas directly above and below the stockpile are considered in runoff computations.

Runoff flow would be in the direction of the nearest waterway, as is true in all drainage basins. It is also assumed that this waterway exists at the boundary of the coal user. This assumption is considered reasonable since electric utilities, which account for 75% of coal consumption (Figure 1), are located near readily available water sources for steam production and power generation.

The representative distance to the boundary of the coal storage area is 86 m (282 ft), Table 13. The area of the stockpile was also calculated previously as 19,792 m^2 (213,000 ft^2). Assuming the pile shape is circular, the diameter of the pile is 159 m (522 ft). With the total runoff area of 144,690 m^2 (1.6×10^6 ft^2), the representative coal storage source area has the theoretical configuration of Figure 8. The total annual pile runoff, 87,500 m^3/yr (3.1×10^6 ft^3), divided by the area, 144,690 m^2 (1.6×10^6 ft^2), is equivalent to an annual runoff of 0.60 m (1.9 ft) or 60 cm/yr (24 in./yr). This value is within 20% of the 51 cm/yr (20 in./yr) figure estimated in Section 3 (22).

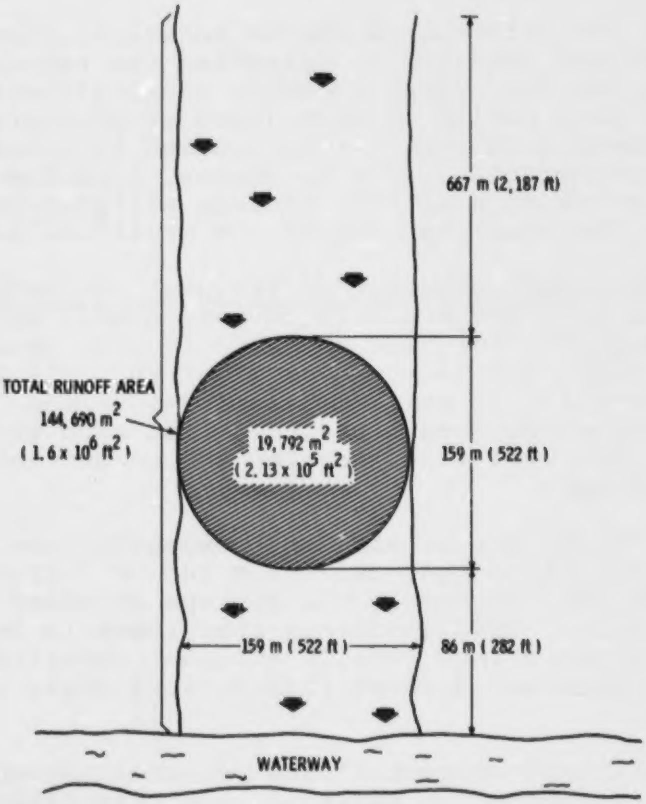

Figure 8. Representative coal storage source area.

EFFLUENT LEVELS

Concentration

Sampling Results--

The simulation apparatus of Figure 3 was employed to acquire concentration values for the pollutants of Table 8 and other water quality parameters studied. These data were compiled through application of the representative rainfall rate (iRP), 0.7 cm/hr (0.27 in./hr), to 9.1-kg (20-lb) coal samples. The pan area (AP) is 1,296.5 cm^2 (201 $in.^2$), yielding a drainage volumetric rate (Vd) of:

$$Vd = iRP \cdot AP \tag{5}$$

$$Vd = \left(\frac{0.7\ \text{cm}}{\text{hr}}\right)(1{,}296.5\ \text{cm}^2)$$

$$= 907.5\ \text{cm}^3/\text{hr}$$

$$= 907.5\ \text{m}\ell/\text{hr (or 0.24 gal/hr)}$$

For each coal and effluent parameter analyzed, average effluent concentrations are required to determine the representative concentration levels. Coals recently mined (fresh), retained in storage for a long period of time (aged or weathered), and moistened from previous rainfalls were studied to obtain average effluent concentrations. In this manner, a random sample reflects the distribution of coal storage effluent concentrations versus time. The sampling results are presented in Appendix C.

Average and Standard Deviation of Effluent Concentrations--

The arithmetic mean and standard deviation effluent concentration levels computed are presented in Table 17. No detectable level (NDL) values were calculated as zero values. All less than values were computed as maximum (possible) values. The background concentrations were subtracted from each effluent concentration level per run. This negates the quantities present in the rainfall water.

The standard deviations of effluent concentrations in Table 17 indicate the variation that can occur due to differences in coals from different coal regions. The average standard deviation of Table 17 is ±211%. This indicates that there is an average deviation of greater than 200% in effluent concentrations from pollutants leached and drained from various coals throughout the United States.

The average effluent concentrations per coal region were calculated and are presented in Table 18. In this table, the Kentucky and Alabama effluent concentrations were averaged to represent the Appalachian coal region. The coal production-weighted effluent concentrations computed are presented in Table 19. These

TABLE 17. ARITHMETIC MEAN AND STANDARD DEVIATION VALUES OF EFFLUENT CONCENTRATION, COAL LEACHATE, AND RUNOFF

Effluent parameter	Effluent concentrations, g/m^3 [a] Arithmetic mean	 Standard deviation
Total suspended solids	1,651	±1,506 (91%)
Total dissolved solids	1,710	±3,756 (220%)
Sulfate	1,505	±3,353 (223%)
Iron	236	±742 (314%)
Manganese	6.7	±15.9 (236%)
Free silica	26	±99 (381%)
Cyanide	0.5	±2.4 (446%)
BOD_5	4.5	±7.2 (160%)
COD	1,303	±1,096 (84%)
Nitrate	0.3	±0.7 (235%)
Total phosphate	NDL[b]	NDL
Antimony	6.1	±10.6 (170%)
Arsenic	11.5	±31.1 (270%)
Beryllium	NDL	NDL
Cadmium	0.07	±0.2 (288%)
Chromium	0.01	±0.025 (250%)
Copper	0.6	±1.6 (284%)
Lead	0.1	±0.15 (124%)
Nickel	2.5	±7.6 (303%)
Selenium	21.3	±31.3 (156%)
Silver	NDL	NDL
Zinc	8.5	±25.0 (294%)
Mercury	0.005	±0.009 (193%)
Thallium	NDL	NDL
pH[c]	5.43[c]	±2.14[c] (39%)
Chloride	0.7	±2.0 (286%)
Total organic carbon	234	±200 (85%)

[a] $g/m^3 = mg/\ell = ppm$.

[b] No detectable level.

[c] Negative logarithm of hydrogen ion concentration.

TABLE 18. AVERAGE EFFLUENT CONCENTRATIONS PER COAL REGION

Effluent parameter	Effluent concentration, g/m^3					
	Appalachian	Great Northern Plains	Interior Eastern	Interior Western	Western	Southwestern
Total suspended solids	1,521	1,282	1,264	1,853	2,486	1,538
Total dissolved solids	259	430	1,136	5,539	1,900	356
Sulfate	66	1,598	648	4,860	240	190
Iron	3.1	1.5	9.1	1,131	8.2	5.5
Manganese	0.03	0.14	0.44	17.9	0.4	0.04
Free silica	12.3	NDL[a]	0.8	86.3	NDL	NDL
Cyanide	<0.001	NDL	0.002	NDL	NDL	NDL
BOD_5	<5.0	<7.5	NDL	<1.2	<2.5	<7.5
COD	1,407	1,324	1,556	1,053	1,826	769
Nitrate	0.12	0.14	0.33	0.09	1.8	0.16
Total phosphate	NDL	NDL	NDL	NDL	NDL	NDL
Antimony	2.1	NDL	7.5	10.3	14.0	6.5
Arsenic	23	1.8	4.1	10.1	5.6	4.1
Beryllium	NDL	NDL	NDL	NDL	NDL	NDL
Cadmium	NDL	NDL	NDL	0.05	0.005	NDL
Chromium	NDL	NDL	NDL	0.03	0.04	NDL
Copper	0.02	NDL	NDL	2.2	NDL	0.02
Lead	0.05	0.05	0.06	0.33	0.07	0.05
Nickel	0.06	0.02	0.09	10.2	0.05	0.03
Selenium	23.8	NDL	12.5	25.2	15.0	21.5
Silver	NDL	NDL	NDL	NDL	NDL	NDL
Zinc	0.008	0.17	0.14	25.0	0.15	0.04
Mercury	<0.001	0.003	NDL	0.004	0.005	0.002
Thallium	NDL	NDL	NDL	NDL	NDL	NDL
pH[b]	6.28[b]	6.93[b]	7.62[b]	2.81[b]	7.24[b]	6.60[b]
Chloride	0.33	NDL	NDL	2.3	NDL	NDL
Total organic carbon	251.7	373.2	380.1	90.5	318.4	158.7

[a] No detectable level. [b] Negative logarithm of hydrogen ion concentration.

TABLE 19. REPRESENTATIVE EFFLUENT CONCENTRATIONS

Effluent parameter	Concentration, g/m^3
Total suspended solids	1,551
Total dissolved solids	754
Sulfate	401
Iron	39
Manganese	0.69
Free silica	10.1
Cyanide	<0.001
BOD_5	<3.8
COD	1,436
Nitrate	0.31
Total phosphate	NDL[a]
Antimony	4.6
Arsenic	15.7
Beryllium	NDL
Cadmium	0.002
Chromium	0.004
Copper	0.08
Lead	0.06
Nickel	3.1
Selenium	19.9
Silver	NDL
Zinc	0.80
Mercury	<0.001
Thallium	NDL
pH	6.78[b]
Chloride	0.27
Total organic carbon	280

[a] No detectable level.

[b] Negative logarithm of hydrogen ion concentration.

values represent undiluted effluent concentrations due to drainage from the representative source. These effluent levels are used in computing runoff concentrations from this source.

Effects of Coal Age and Rainfall Frequency--
The average effluent concentrations for the fresh Kentucky and aged Missouri coals were calculated per simulation run to compare results between fresh and aged coals. The effect of rainfall frequency from each run was also observed. These average values are presented in Table 20.

Table 20 shows a general trend for fresh coals: increasing rainfall frequency increases the effluent concentrations. Aged coal, however, has consistently higher levels than fresh coal. The highest effluent concentrations therefore tend to occur near

TABLE 20. EFFLUENT CONCENTRATIONS VERSUS RAINFALL FREQUENCY FOR AGED AND FRESH COALS

	Effluent concentration, g/m^3					
	First run last rainfall ≥30 days		Third run last rainfall 14 days		Second run last rainfall 1 day	
Effluent parameter	Fresh coal	Aged coal	Fresh coal	Aged coal	Fresh coal	Aged coal
Total suspended solids	724	1,656	1,206	1,943	5,396	5,176
Total dissolved solids	200	16,372	375	4,836	336	5,488
Sulfate	67	14,472	58	3,899	121.5	4,896
Iron	0.4	3,099	2.6	1,400	7.7	990
Manganese	NDL[a]	55	0.05	13	0.01	16
Free silica	NDL	436	0.6	3.3	94.7	NDL
Cyanide	NDL	NDL	0.006	0.006	NDL	0.01
BOD_5	<5	NDL	NDL	NDL	<25	<15
COD	591	1,092	1,079	988	4.6	2,876
Nitrate	0.04	NDL	0.2	0.14	0.14	0.16
Total phosphate	NDL	NDL	NDL	NDL	NDL	NDL
Antimony	NDL	11	NDL	0.009	15	37
Arsenic	0.14	26	0.02	0.016	3.4	10.3
Beryllium	NDL	NDL	NDL	NDL	NDL	NDL
Cadmium	NDL	0.9	NDL	0.3	NDL	0.3
Chromium	NDL	NDL	NDL	0.08	NDL	NDL
Copper	NDL	7.0	0.06	2.0	0.17	2.2
Lead	0.07	0.5	0.05	0.5	0.11	0.3
Nickel	0.06	33	0.05	6.5	0.14	9.7
Selenium	0.08	59	NDL	NDL	87	67
Silver	NDL	NDL	NDL	NDL	NDL	NDL
Zinc	NDL	107	0.05	31	0.04	31
Mercury	0.02	0.009	NDL	NDL	NDL	NDL
Thallium	NDL	NDL	NDL	NDL	NDL	NDL
pH	6.4[b]	2.4[b]	5.9[b]	2.7[b]	6.4[b]	2.6[b]
Chloride	NDL	8.9	NDL	1.8	2.3	1.0
Total organic carbon	174	39.2	397	306	63.2	3.1

[a] No detectable level.

[b] Negative logarithm of H^+ concentration.

stockpiles of aged coals in regions of frequent rainfall. The quantitative effect of these parameters was not established since it was beyond the scope of this study.

Sampling, Analytical, and Quality Control Effects--
During the third simulation run, three coal drainage samples were taken from the same coal (Kentucky) and analyzed. These results provide data on the deviation of results due to sampling, analysis, and quality control factors. The arithmetic mean and standard deviation of the results of Table C-4, Appendix C, for Kentucky coal are presented in Table 21. The average deviation of the measurement values of Table 21 is ±29%. Deviations for solids and iron are high. However, drains were placed in different areas of the pan (Figure 3) for different samples. Greater quantities of solids may be present in one area of the pan versus another, thus explaining the differences in concentration values.

TABLE 21. PRECISION OF CONCENTRATION MEASUREMENTS

Effluent parameter	Arithmetic mean, g/m^3	Standard deviation, g/m^3
Total suspended solids	1,209	±803 (66%)
Total dissolved solids	407	±379 (93%)
Sulfate	61	±8.5 (14%)
Iron	2.9	±1.4 (48%)
Manganese	0.08	±0.02 (33%)
Free silica	2.3	±0.23 (10%)
Cyanide	0.006	–[a]
BOD_5	<5	±0
COD	1,083	±866 (80%)
Nitrate	0.21	0.006 (3%)
Total phosphate	NDL[b]	NDL
Antimony	0.0005	±0
Arsenic	0.023	0.004 (15%)
Beryllium	NDL	NDL
Cadmium	NDL	NDL
Chromium	NDL	NDL
Copper	0.12	±0.004 (15%)
Lead	0.08	±0.006 (8%)
Nickel	0.06	±0.006 (10%)
Selenium	0.002	±0
Silver	NDL	NDL
Zinc	0.14	±0.017 (12%)
Mercury	NDL	NDL
Thallium	NDL	NDL
pH	5.89[c]	±0.02[c] (3%)
Chloride	NDL	NDL
Total organic carbon	401	±267 (67%)

[a] Only one value detected in three samples.

[b] No detectable level.

[c] Negative logarithm of hydrogen ion concentration.

Worst Case Levels--
The deviation for each effluent (Table 21) can be used to adjust the undiluted effluent concentrations applied to the representative source (Table 19). The upper standard deviation level was applied to each effluent to skew the levels on the higher side. These adjusted effluent concentrations are presented in Table 22.

TABLE 22. WORST CASE EFFLUENT CONCENTRATIONS AT THE REPRESENTATIVE SOURCE

Effluent parameter	Effluent concentration, g/m^3
Total suspended solids	2,575
Total dissolved solids	1,455
Sulfate	457
Iron	58
Manganese	0.92
Free silica	11.1
Cyanide	<0.001
BOD_5	<3.8
COD	2,185
Nitrate	0.32
Total phosphate	NDL[a]
Antimony	4.6
Arsenic	18.0
Beryllium	NDL
Cadmium	0.002
Chromium	0.004
Copper	0.11
Lead	0.06
Nickel	3.4
Selenium	19.9
Silver	NDL
Zinc	1.1
Mercury	<0.001
Thallium	NDL
pH	6.78[b]
Chloride	0.27
Total organic carbon	468

[a] No detectable level.

[b] Negative log (H^+).

Organic Effluents--
From the results of runs 1 and 2, the sample with the highest total organic carbon (TOC) content (sample A-1, Appendix C) was analyzed for the species listed in Table 8. Results from run 3 were not used since they were obtained late in the study. The

highest TOC level was chosen to increase the probability of detecting these species. The results of these analyses yielded the effluent concentrations in Table 23. These levels indicate the drainage directly from the coal pan. The background concentration levels are also listed in Table 23, along with the resultant concentration levels attributed to coal stockpile drainage (source levels).

TABLE 23. ORGANIC EFFLUENT CONCENTRATIONS

Compound	Concentration, 10^{-3} g/m^3 [a] Coal leachate	Background	Source level
2-Chloronaphthalene	16	2	14
Acenaphthene	22	7	15
Fluorene	21	7	14
Fluoranthene	24	8	16
Benzidine	18	4	14
Di-iso-octylphthalate (DiOP)	95	405	-310[b]
Benzo(ghi)perylene	52	8	44

[a] $10^{-3}g/m^3 = \mu g/\ell$ = ppb.

[b] Negative level due to higher concentration in the background sample, believed due to contact with plastic for longer period of time than leachate sample; DiOP is a plasticizer.

Only those substances on the EPA toxic substances list (Table 8) were analyzed (27). Other organics were present in the analyses. A discussion of the analytical methodology and results is presented in Appendix D. No phenolic compounds were observed at greater than or equal to $10^{-3}g/m^3$. The background level of di-iso-octylphthalate (DiOP) was higher than the level drained through the coal sample. This is assumed to have resulted from DiOP contact with the plastic liner used in the sample pans. In the background pan this liner was in contact with the rainfall for longer periods of time. This is believed to have caused the higher levels of di-iso-octylphthalate since it is a plasticizer.

The concentrations of all these effluents as they enter the nearest waterway are determined in the following discussion. These values are computed for the representative stockpile size of 95,000 metric tons (104,720 tons) at a runoff distance of 87 m (282 ft) and runoff rate of 629 m^3/hr (2,221 ft^3/hr).

Rates, Factors, and Runoff Concentrations

The effluent rates (Qe) from coal leachate and drainage are the product of the simulated rainfall volume (Vd) and the concentration levels for each effluent parameter (C_k) (Table 22).

Rainfall intensity (iR) adjusted to the representative level of 0.7 cm/hr (0.27 in./hr), resulted in Vd equals 907.5 mℓ of rainfall per hour (0.24 gal/hr). Effluent rates are determined for each parameter (k) of Table 19, except pH, as

$$Qe = Vd \cdot C_k \tag{6}$$

and are listed in Table 24.

TABLE 24. EFFLUENT RATES FROM THE REPRESENTATIVE SOURCE

	Effluent rate	
Effluent parameter	mg/hr	10^{-3} lb/hr
Total suspended solids	1,408	2.8
Total dissolved solids	685	1.4
Sulfate	364	0.73
Iron	35	0.07
Manganese	0.63	0.001
Free silica	5.1	0.01
Cyanide	<0.001	2×10^{-6}
BOD$_5$	<3.5	0.007
COD	1,304	2.6
Nitrate	0.3	6×10^{-4}
Total phosphate	NDL[a]	NDL
Antimony	4.2	0.008
Arsenic	14.3	0.03
Beryllium	NDL	NDL
Cadmium	0.002	4×10^{-6}
Chromium	0.004	8×10^{-6}
Copper	0.07	1.4×10^{-4}
Lead	0.05	1×10^{-4}
Nickel	2.8	0.006
Selenium	18.1	0.04
Silver	NDL	NDL
Zinc	0.73	0.001
Mercury	0.0009	1.8×10^{-6}
Thallium	NDL	NDL
pH	6.58[b]	6.58[b]
Chloride	0.24	0.0005
Total organic carbon	254	0.5

[a] No detectable level.

[b] Remains the same.

Leaching factors (L_{fk}) computed per coal region per element (k) are the percentage of each kth element present in the coal that is leached out per hour of rainfall. These factors are the product of effluent concentration, C_k (Table 17), and applied rainfall volume (Vd) divided by the average weight of the element in the coal ($\overline{W}_k$), such that:

$$L_{fk} = \frac{C_k \cdot Vd}{\overline{W}_k} \tag{7}$$

The average weight of the kth element in coal is the product of the average percent of the element in coal, $\overline{P}_k$ (Table 11), and the weight of the coal subjected to the simulation rainfall, iRP, which was 9,072 grams (s equals 20 pounds where s is the weight of coal sample in simulator pan). The value of $\overline{W}_k$ is computed as:

$$\overline{W}_k = \overline{P}_k \cdot iRP \tag{8}$$

Leaching factors (L_{fk}), computed from Equation 7 for each coal region, are presented in Table 25. Specific chemical analyses of each coal placed under the simulator were beyond the scope and finances of this study. Lack of data on element content or non-detectable wastewater levels prohibited computation of greater than 50% of the leaching factors for Table 25.

TABLE 25. LEACHING FACTORS PER COAL REGION

	Leaching factor, percent of element leached per hour of average rainfall					
Element	Appalachian	Interior Eastern	Interior Western	Great Northern Plains	Southwestern	Western
Antimony	2.1	-[a]	-[a]	-[a]	-[a]	-[a]
Arsenic	0.74	3.7	-[a]	0.02	0.56	14.0
Free silica	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]
Beryllium	NDL[b]	NDL	NDL	NDL	NDL	NDL
Cadmium	NDL	NDL	-[a]	NDL	NDL	-[a]
Chromium	NDL	NDL	0.02	NDL	NDL	0.06
Copper	0.013	NDL	18.3	NDL	0.002	NDL
Cyanides	-[a]	-[a]	-[a]	-[a]	-[a]	-[a]
Lead	0.055	0.054	0.82	0.07	0.08	0.09
Mercury	0.066	NDL	0.20	0.43	0.15	0.71
Nickel	0.04	0.06	6.0	0.03	0.05	0.09
Silver	NDL	NDL	NDL	NDL	NDL	NDL
Thallium	NDL	NDL	NDL	NDL	NDL	NDL

[a] No data available on average element content.

[b] No detectable levels in wastewater.

Leaching factors are useful in studying the removal of inorganics within coal versus time. This study allowed the examination of one data point versus time; a more detailed study may indicate the relationship that exists and allow analysis of the coal tested. Such analysis may explain the anomalies in leaching factors in coals from various coal regions (Table 25). However, there is consistency in lead, mercury, and nickel leaching factors. It was for these elements that the greatest amount of information on trace element content was available, which may be the reason for this consistency.

Effluent factors (E_{fk}) from coal storage areas are essentially unrelated to production quantities. Emission rates are utilized to compute these values as:

$$E_{fk} = \frac{Qe}{s} \qquad (9)$$

However, during a rainfall, only 15% of the water volume striking the stockpile is actually drained from the coal. Each factor is therefore adjusted to reflect this mass retention. The average effluent factors per coal region were calculated from Equation 9 and are presented in Table 26.

The effluent factors, rates, and concentration levels presented in this section represent levels at the source. The coal production-weighted effluent factors computed for each element are listed in Table 27. These factors are used in computing concentrations downstream from the representative source.

Average mass emission quantities were computed for each effluent parameter by considering the product of the representative effluent factors (Table 26), hours of rain per year (139), and the total amount of coal stockpiled per year. These values are presented in Table 28. A total of 690.7 x 10^3 metric tons (76 x 10^3 tons) of effluents are emitted, which represents 0.58% of the total coal stockpiled per year.

Runoff concentrations for the representative source were computed at the representative distance of 86 m. In Section 4, the runoff quantity from the stockpile was determined to be 21 m^3/hr (742 ft^3/hr) for the representative source (Figure 8). The runoff level from the entire drainage basin (minus pile area) was 610 m^3/hr (21,436 ft^3/hr). Therefore the effluent factors of Table 27 were applied to a representative stockpile of 95,000 metric tons (105,000 tons, Section 3 to obtain the weighted effluent rate. This quantity was divided by the runoff volume of the stockpile (21 m^3/hr) to obtain the concentration at the source. This concentration level was then diluted by the rainfall from the entire drainage basin (608 m^3/hr) to obtain the runoff concentration levels for the representative source, Table 29.

TABLE 26. AVERAGE EFFLUENT FACTORS PER COAL REGION

	Effluent factors, mg/kg-hr (10^{-3} lb/ton-hr)											
	Appalachian		Interior Eastern		Interior Western		Great Northern Plains		Southwestern		Western	
Effluent parameter	mg/kg-hr	10^{-3} lb/ton-hr	mg/kg-hr	10^{-3} lb/ton-hr	mg/kg-hr	10^{-3} lb/ton-hr	mg/kg-hr	10^{-3} lb/ton-hr	mg/kg-hr	10^{-3} lb/ton-hr	mg/kg-hr	10^{-3} lb/ton-hr
Total suspended solids	23	46	19	38	28	56	19	38	23	46	37	74
Total dissolved solids	4	8	17	34	83	166	6	12	5	10	28	56
Sulfate	1	2	10	20	73	446	24	48	3	6	4	8
Iron	0.04	0.08	0.1	0.2	17	34	0.03	0.06	0.09	0.18	0.1	0.2
Manganese	0.0004	0.0008	0.006	0.012	0.3	0.6	0.002	0.004	0.0006	0.0012	0.006	0.012
Free silica	0.2	0.4	0.01	0.02	1.4	2.8	NDL[a]		NDL		NDL	
Cyanide	<0.00001	<0.00002	0.00003	0.00006	NDL		NDL		NDL		NDL	
BOD_5	<0.08	<0.16	NDL		<0.02	<0.04	0.1	0.2	0.1	0.2	<0.03	<0.06
COD	21	42	23	46	16	32	20	40	12	24	27	54
Nitrate	0.002	0.004	0.004	0.008	0.001	0.002	0.002	0.004	0.003	0.006	0.03	0.06
Total phosphate	NDL		NDL		NDL		NDL		NDL		NDL	
Antimony	0.03	0.06	0.1	0.2	0.2	0.4	NDL		0.09	0.18	0.2	0.4
Arsenic	0.3	0.6	0.06	0.12	0.2	0.4	0.03	0.06	0.06	0.12	0.09	0.18
Beryllium	NDL		NDL		NDL		NDL		NDL		NDL	
Cadmium	NDL		NDL		0.0008	0.0016	NDL		NDL		0.00007	0.00014
Chromium	NDL		NDL		0.0004	0.0008	NDL		NDL		0.0006	0.0012
Copper	0.0003	0.0006	NDL		0.03	0.06	NDL		0.0003	0.0006	NDL	
Lead	0.0008	0.0016	0.0009	0.0018	0.004	0.008	0.0008	0.0016	0.0008	0.0016	0.001	0.002
Nickel	0.0009	0.0018	0.001	0.002	0.2	0.4	0.0003	0.0006	0.0004	0.0008	0.0008	0.0016
Selenium	0.4	0.8	0.2	0.4	0.4	0.8	NDL		0.3	0.6	0.2	0.4
Silver	NDL		NDL		NDL		NDL		NDL		NDL	
Zinc	0.0001	0.0002	0.002	0.004	0.4	0.8	0.003	0.006	0.006	0.0012	0.003	0.006
Mercury	0.00002	0.00004	NDL		0.00006	0.00012	0.00004	0.00008	0.00003	0.00006	0.00008	0.00016
Thallium	NDL		NDL		NDL		NDL		NDL		NDL	
Chloride	0.004	0.008	NDL		0.03	0.06	NDL		NDL		NDL	
Total organic carbon	4	8	6	12	1	2	6	12	2	4	5	10
pH (log $1/H^+$)	6.3		7.6		2.8		6.9		6.6		7.2	

[a] No detectable level.

NOTE: Blanks indicate no data applicable.

TABLE 27. EFFLUENT FACTORS FOR THE REPRESENTATIVE SOURCE

Effluent parameter	Coal production-weighted effluent factor mg/kg-hr	lb/10^3 ton-hr
Total suspended solids	23	46
Total dissolved solids	11	22
Sulfate	6	12
Iron	1	2
Manganese	0.01	0.02
Free silica	0.2	0.4
Cyanide	<0.00002	<0.00004
BOD_5	<0.06	<0.12
COD	22	44
Nitrate	0.004	0.008
Total phosphate	NDL[a]	NDL
Antimony	0.06	0.12
Arsenic	0.2	0.4
Beryllium	NDL	NDL
Cadmium	0.00003	0.00006
Chromium	0.00006	0.00012
Copper	0.001	0.002
Lead	0.0009	0.0018
Nickel	0.006	0.012
Selenium	0.3	0.6
Silver	NDL	NDL
Zinc	0.01	0.02
Mercury	0.00002	0.00004
Thallium	NDL	NDL
Total organic carbon	0.4	0.8
pH	6.6[b]	6.6[b]
Chloride	0.003	0.006

[a] No detectable level.

[b] Log $1/H^+$, remains the same.

TABLE 28. MASS ANNUAL EFFLUENT EMISSIONS FROM COAL STOCKPILES, 1975

Effluent parameter	Mass emissions 10^3 metric tons/yr	tons/yr
Total suspended solids	377	415,571
Total dissolved solids	180	198,416
Sulfate	98	108,027
Iron	16	17,637
Manganese	0.2	220
Free silica	3.3	3,638
Cyanide	<0.0003	0.3
Nitrate	0.06	66
Total phosphate	NDL[a]	NDL
Antimony	1.0	1,102
Arsenic	3.3	3,638
Beryllium	NDL	NDL
Cadmium	0.005	0.6
Chromium	0.0019	1.1
Copper	0.02	22
Lead	0.01	11
Nickel	0.1	110
Selenium	4.9	5,401
Silver	NDL	NDL
Zinc	0.2	220
Mercury	0.0003	0.3
Thallium	NDL	NDL
Total organic carbon	6.6	7,275
Chloride	0.05	55
TOTAL	690.7	761,366

[a] No detectable level.

TABLE 29. RUNOFF CONCENTRATIONS OF INORGANICS AND WATER QUALITY PARAMETERS FROM THE REPRESENTATIVE SOURCE

Effluent parameter	Concentration entering waterways, g/m^3
Total suspended solids	0.16
Total dissolved solids	0.08
Sulfate	0.04
Iron	0.007
Manganese	7×10^{-5}
Free silica	0.001
Cyanide	$<1 \times 10^{-7}$
Nitrate	3×10^{-5}
Total phosphate	NDL[a]
Antimony	4×10^{-4}
Arsenic	0.001
Beryllium	NDL
Cadmium	2×10^{-7}
Chromium	4×10^{-7}
Copper	7×10^{-6}
Lead	6×10^{-6}
Nickel	4×10^{-5}
Selenium	0.002
Silver	NDL
Zinc	7×10^{-5}
Mercury	1×10^{-7}
Thallium	NDL
Chloride	2×10^{-5}
Total organic carbon	0.003

[a] No detectable level.

For pH values, the representative level at the source was 6.6. Assuming rainfall has a pH of 7, a runoff pH level is computed by weighting these two pH values by their respective rainfall volumes. The pile receives 2,919 m^3/yr (700 ft^3/yr) of rainfall, which is 139 hr/yr x 21 m^3/hr. The surrounding area receives 87,479 m^3/yr (3,100 ft^3/yr). The pH level at runoff to the stream is thus a weighted value of greater than 6.9.

The BOD level as it leaves the coal stockpile is less than 3.8 g/m^3; however, it is believed that the wastewater may have been toxic to the BOD test seed. Since high levels for COD and TOC were obtained, the BOD levels obtained from the test coals are not consistant with these data. Regardless of this consideration, oxygen depletion due to the leachate is insignificant.

The low levels of effluents (Table 29) result from the fact that those elements concentrated within coal are associated primarily with the organic portion. Elements tend to be associated with the coal and not with the waste from cleaning (1). In addition, the coal stockpile itself acts as an absorption and filtration medium. Absorption of the water reduces the level of effluent runoff by an estimated 85%. Filtration of solids with coal is a current wastewater treatment method (33). The values computed for Table 29 also assumed a complete mixing of runoff waters prior to discharge to the waterway. This is considered valid since runoff from areas upstream of the stockpile have time to reach and mix with the pile drainage. This occurs because of the time lag from onset of rainfall to pile drainage (see Figure 7) caused by retention of rainfall within the coal pile structure.

The runoff concentrations of organics were computed directly from the dilution by 629 m^3/hr (22,210 ft^3/hr) of precipitation. The levels at the representative source (Table 22) were thus diluted to produce the calculated concentrations that run off into waterways listed in Table 30. These values are used for comparison with the hazardous concentration levels.

TABLE 30. RUNOFF CONCENTRATIONS OF ORGANICS FROM THE REPRESENTATIVE SOURCE

Effluent	Runoff concentration entering waterways, 10^{-6}g/m^3[a]
2-Chloronaphthalene	0.02
Acenaphthene	0.02
Fluorene	0.02
Fluoranthene	0.02
Benzidine	0.02
Di-iso-octylphthalate	–[b]
Benzo(ghi)perylene	0.07

[a] 10^{-6}g/m^3 = ng/ℓ = ppt.

[b] Assumed to be within the background water (Table 23).

Previous Studies

Previous studies of coal pile leachate and runoff were performed by the Tennessee Valley Authority (TVA) (personal communication with D. M. Cox, Tennessee Valley Authority, Division of Environmental Planning, Chattanooga, Tennessee, 10 January 1977), the Pickard and Anderson Company (17), and the U.S. Environmental Protection Agency (23). The arithmetic mean and range values for these studies are presented in Table 31.

TABLE 31. COAL STOCKPILE EFFLUENT CONCENTRATIONS FROM PREVIOUS STUDIES (17, 23, a) (g/m^3)

	Arithmetic mean			Range		
Parameter	TVA study	Pickard-Anderson	EPA	TVA Study	Pickard-Anderson	EPA
pH[b]	2.8		4.4	2.3 to 3.1	2.2 to 5.8	2.1 to 7.8
TSS[c]	470		699	8 to 2,300		22 to 3,302
TSD[d]		11,745	12,607		9,332 to 14,948	247 to 44,050
Sulfate	5,200		6,879	1,800 to 9,600		133 to 21,920
Acidity		2,562	9,908		375 to 8,250	8.68 to 27,810
Iron	940	490	10,856	240 to 1,800	139 to 850	0.06 to 93,000
Manganese	2,900	17.1		9 to 4,500	4.5 to 72.0	
Magnesium	220		131.5	1 to 480		89 to 174
Antimony						
Arsenic	0.17			0.01 to 0.6		
Asbestos						
Beryllium	–[e]			–[e]		
Cadmium	–[e]			–[e]		
Cromium	–[e]	2.6	2.71	–[e]	0.1 to 7.5	0 to 15.7
Copper	0.86	1.69	2.1	0.3 to 1.4	0.1 to 6.1	1.6 to 3.4
Cyanides						
Lead	–[e]			–[e]		
Mercury						
Nickel	2.6			0.7 to 4.3		
Selenium	0.006			0.001 to 0.03		
Gold						
Thallium						
Zinc	6.7	5.9	5.89	2 to 16	2.4 to 26	0.006 to 23
Aluminum	260		1,012.5	66 to 440		825 to 1,200
Calcium	300			31 to 490		
Ammonia			0.7			0 to 1.77
Alkalinity			20			0 to 82
Biochemical oxygen demand			3			0 to 10
Chemical oxygen demand			830			85 to 1,099
Nitrate			1.31			0.3 to 2.25
Phosphorus			0.72			0.23 to 1.2
Turbidity			205.5			2.77 to 505
Total hardness			805			130 to 1,850
Chloride			127.8			3.6 to 481
Sodium			893			160 to 1,260

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[a] Personal communication with D. M. Cox.

[b] pH; reciprocal of log (H^+).

[c] Total suspended solids.

[d] Total dissolved solids.

[e] Less than the detection limit per EPA methodology.

Note.—Blanks indicate data not available.

Results of the Pickard and Anderson study covered a 21-day monitoring period. For the eight parameters monitored, the deviations of values shown in Table 32 were observed. From Table 31 it can be seen that these effluent concentrations can vary up to 129% over 21 days. Effluent concentrations therefore vary ±129% at the source and average a ±211% deviation (Table 17) between sources. Therefore, defining a representative source is justified considering the possible variability of results.

TABLE 32. DEVIATIONS OF EFFLUENT CONCENTRATIONS OVER A 21-DAY PERIOD

Parameter	Number of values	Effluent concentration, g/m^3 Arithmetic mean	Effluent concentration, g/m^3 Standard deviation
pH[a]	146	3.3	0.97 (29%)
Total iron	137	1,828	2,362 (129%)
Acidity[b]	45	6,408	8,090 (126%)
TDS	7	15,588	10,498 (67%)
Copper	22	2.4	2.8 (116%)
Manganese	22	21.8	26.5 (122%)
Chromium	21	3.2	2.8 (90%)
Zinc	21	8.7	11 (126%)

[a] pH; reciprocal of log (H^+).

[b] g/m^3 of $CaCO_3$.

MRC[a] performed two preliminary analyses of coal pile runoff. One was based on physically sampling the drainage from a coal pile and the other on coal submerged in distilled water for a period of 2 weeks. This was accomplished on coal that was later used for the rainfall simulation studies. Results indicated the order-of-magnitude presence of trace metals and TOC within the filtered leachate. These values are presented in Table 33. The resultant TOC level of 254 g/m^3 was high enough to justify further TOC analyses of leachate and drainage from the simulation studies. The trace metal studies indicated low concentrations of metals (except aluminum, calcium, and magnesium) within the leachate. However, the wide disparity in metal content for coals from different regions would not justify the exclusion of trace metal analyses from our study. If a number of the metals were not detected then further analyses may not have been warranted.

The runoff concentrations from the study (Table 29) are from one to seven orders of magnitude less than the concentrations reported in Table 31. This disparity is accounted for by the fact that the previous studies were conducted directly at the source (that is, samples were obtained on or near the pile in the drainage ditches). These values therefore do not account for the dilution that occurs as the runoff approaches the nearest waterway. This dilution results from the rainfall in the entire drainage area, not just at the pile surface. However, the diluted values (Table 29) as they enter the nearest waterway are of prime concern since these levels affect the health of aquatic lifeforms. If the values of Table 22 were computed only for the runoff from the stockpile surface area, the concentrations would increase by six orders of magnitude. The results of this study would then compare well with those of previous studies. A numerical comparison cannot be performed since previous studies failed to record the actual distance from the source at which sampling occurred. In addition, since the effluent concentrations are site-specific, a comparison of the hypothetical representative source with particular stockpile studies is futile.

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[a] Monsanto Research Corporation.

TABLE 33. PRELIMINARY ANALYSES OF TRACE METALS AND TOC LEVELS

Component	Concentration, g/m^3		Component	Concentration, g/m^3	
	Submerged	Drainage		Submerged	Drainage
Silver	None	3	Molybdenum	≤0.1[a]	≤0.1[a]
Aluminum	18.3	90	Sodium	5.8	≤0.1[a]
Barium	None	None	Nickel	0.2	4
Boron	≤0.1[a]	-[b]	Lead	≤0.1[a]	≤0.1[a]
Calcium	5	203	Antimony	≤0.1[a]	2
Cadmium	≤0.1[a]	≤0.1[a]	Silicon	5	≤0.1[a]
Cobalt	≤0.1[a]	≤0.1[a]	Tin	≤0.1[a]	≤0.1[a]
Chromium	≤0.1[a]	≤0.1[a]	Strontium	0.1	≤0.1[a]
Copper	0.1	≤0.1[a]	Titanium	≤0.1[a]	≤0.1[a]
Iron	2	26	Vanadium	0.3	≤0.1[a]
Magnesium	21.7	144	Zinc	1.8	2
Manganese	0.6	8	Phosphorus	0.2	4
Selenium	-[b]	≤0.1[a]	Total Organic Carbon	254	-[b]
Arsenic	-[b]	≤0.1[a]			

[a] Detection limit.

[b] No analyses performed.

WATER QUALITY DEGRADATION

Regulations

Under the authority of the Federal Water Pollution Control Act (PL92-500), effluent limitations for drainage from coal storage areas were proposed for the coal mining and established for the steam electric power generating point sources. For coal mining, effluent limitations were first established as interim final rules in the 17 October 1975 Federal Register (34). Rules were proposed for BPCTCA (best practicable control technology currently available, BATEA (best available technology economically achievable), and for new sources in 1976 (35). These limitations applied to coal storage areas at preparation plants with any discharges pumped, siphoned, or drained. They include any pollutants 1) frequently present in concentrations deleterious to aquatic life, 2) for which technology existed for reduction or removal, and 3) for which research indicated capabilities of disrupting aquatic systems (35). Interim final rules were first established in 1975 for permit purposes.

The 1976 proposals for BPCTCA were established in April of 1977 (36). The fact that inclusion of pollutants was based on their effect on aquatic life further justifies the use of runoff concentrations into waterways for observing hazard potential. Final effluent limitations and guidelines for BATEA and new sources are slated to be published in September of 1978 (37). Best practicable control technology currently available for coal storage areas at preparation plants are discussed in the development document for the coal mining source and Section 5 of this report (38). Effluent limitations guidelines for runoff from material storage piles at steam electric power generating sources are the same for BPCTCA, BATEA, and new stockpile sources (39).

A comparison of the calculated runoff concentration levels of Table 29 with the existing and proposed standards for coal storage areas is presented in Table 34 (37, 40). The computed runoff levels from the representative source are all two to five orders of magnitude less than the effluent limitations. If samples were taken at the source, the concentration levels for iron and TSS from the representative source would exceed these limitations. Runoff concentration levels are used for comparison instead, because the effluent limitations, as stated, are concerned with effects on aquatic organisms. Therefore, the representative source would comply with the regulations.

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(34) Part IV: Environmental Protection Agency - Coal Mining Point Source Category - Interim Final Rules. Federal Register, 40(202):48830-48840, 1975.

(35) Chapter 1 - Environmental Protection Agency - Part 434 - Coal Mining Point Source Category - Effluent Guidelines and Standards. Federal Register, 41(94):19832-19843, 1976.

(36) Environmental Protection Agency - Coal Mining Point Source Category - Effluent Guidelines and Standards. Federal Register, 42(80):21379, 1977.

(37) Calendar of EPA Regulations Under Consideration. Pollution Engineering, Yearbook and Product Reference Guide, 28 February 1977. pp. 16-18.

(38) Development Document for Interim Final Effluent Limitations Guidelines and New Source Performance Standards for the Coal Mining Point Source Category. EPA-440/1-76/057-a. U.S. Environmental Protection Agency, Washington, D.C., May 1976. pp. 95-96.

(39) Environmental Protection Agency - Part 423 - Steam Electric Power Generating Point Source Category - Effluent Guidelines and Standards. Federal Register, 39(196):36206-36207, 1974.

Toxicity

To establish whether the runoff concentrations entering a waterway are detrimental to aquatic life, hazardous concentration levels must be established for each effluent. Since a standardized methodology or reference of hazardous levels does not exist, a number of sources are used to obtain these values.

"Hazardous" is a general term which is applied in this context to specific detrimental effects observed on the life of tested organisms. These concentration levels are reported in drinking water standards and water quality criteria, or are calculated from test data. Ideally, information on a large percent of all aquatic species would show community responses to a range of concentrations over a long period of time. However, this information is not available. Therefore, hazardous concentrations are calculated from several equations relating the results of specific tests (40-42). Tests record the lethal doses (LD_{50}) and concentrations (LC_{50}) lethal to 50% of the test species (43). These data are used to represent the expected effects on all other organisms. Test species are chosen on the basis of their availability, importance to man, and physiological responses to the laboratory environment.

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(40) Walden, C. C., and T. E. Howard. Toxicity: Research and Regulation. In: Proceedings of 1976 TAPPI Environmental Conference, Atlanta, Georgia, April 26-28, 1976. pp. 93-99.

(41) Handy, R. W., and M. Samfield. Estimation of Permissible Concentrations of Pollutants for Continuous Exposure; Part II: Permissible Water Concentrations. Contract 68-02-1325, Task 34, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1975. 76 pp.

(42) TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1975. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1975. 97 pp.

(43) The Toxic Substances List - 1974. HSM 99-73-45, National Institute for Occupational Safety and Health, Rockville, Maryland, June 1974. 904 pp.

TABLE 34. COMPARISON OF RUNOFF CONCENTRATION LEVELS WITH EFFLUENT LIMITATIONS (38, 39) (g/m^3)

	Coal mining point sources						Steam electric power generating based on BPCTCA, BATEA, and for new sources	Runoff concentration
	Based on BPCTCA		Proposed, based on BATEA		Proposed, new sources			
Effluent parameter	Maximum for 1 day	Average of 30 days	Maximum for 1 day	Average of 30 days	Maximum for 1 day	Average of 30 days		
Total iron	7.0	3.5	3.5	3	3.5	3.0	-[a]	0.007
Total manganese	4.0	2.0	4.0	2	4	2	-[a]	0.00007
TSS	70	35	40	20	70	35	≤50	0.16
pH	Within 6 to 9 range	Within 6 to 9 range	Within 6 to 9 range	Within 6 to 9 range	Within 6 to 9 range	Within 6 to 9 range	Within 6 to 9 range	6.9

[a] No limitation promulgated at present.

The most preferred equation is the result of an effluent concentration, below, which exerted no stress on aquatic organisms. This concentration is about 5% to 10% of the 96-hr LC_{50} value (40). However, LC_{50} values for 48 hr may be used in the absence of LC_{50} (96-hr) data. Assuming a human consumes 2 ℓ (0.53 gal) of water per day, 0.2% of LD_{50} (oral/rat) values may be used to represent the maximum concentration that has no effect on human health. This same percentage may be applied to LD_{50} other than oral/rat or other toxicity indicators (41). Threshold limit values (TLVs®) are used to determine hazardous water concentrations by assuming 10 m^3 (353 ft^3) of air in 8 hr will contain the amount of contaminant in 2 ℓ (0.53 gal) of water, and multiplying the TLV by 0.77% (42). However, most toxicity tests are not conducted for the purpose of industrial effluent assessment, and practically no information exists on the hazardous properties of complex effluents or mixtures. The above relationships provide a methodology for computing hazardous concentrations for specific pollutants.

The hazardous concentration values computed for the inorganic effluents emitted from coal stockpiles are compiled in Table 35 (40, 41, 43, 44). The ratio of the runoff concentration to the hazardous concentration for each effluent is presented in the third column. The runoff concentration ranges from one to seven orders of magnitude less than the hazardous value. The highest ratio, 0.2, is for selenium. All but three of the hazardous concentration values are obtained directly from EPA water quality criteria (44). No ratios exceed those for the representative source.

Hazardous concentrations and ratios for other pollutants not listed in Table 35 or covered by effluent regulations are listed in Table 36. The ratio of runoff concentration, C_R, to hazardous concentration shows levels four to six orders of magnitude less than hazardous levels. These water quality parameters also do not exceed a ratio (C_R/C_H) of one.

Within the organic toxic substance list, the pesticides were excluded from study (due to the improbability of their occurrence within coal). The organics found in the coal pile wastewater (Table 23) are compared to hazardous concentration levels or standards. Hazardous concentrations are determined from the same equations used to generage the levels for inorganics listed in Table 35. A comparison of the hazardous concentrations (C_H) with the runoff concentrations (C_R) is presented in Table 37. The runoff concentrations are from 6 to 11 orders of magnitude less than the hazardous levels.

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(44) Quality Criteria for Water. EPA-440/9-76-023, U.S. Environmental Protection Agency, Washington, D.C., July 1976. 501 pp.

TABLE 35. HAZARDOUS AND RUNOFF CONCENTRATION LEVELS FOR INORGANIC POLLUTANTS FROM COAL STORAGE AREAS

Effluent	Runoff concentration, g/m^3	Hazardous concentration, g/m^3	C_R/C_H ratio
Antimony	0.0004	0.225 (40, 43)	0.0018
Arsenic	0.001[a]	0.05 (44)	0.02
Asbestos	0.001	0.63 (40, 43)	0.0016
Beryllium	NDL[b]	0.011 (44)	–[c]
Cadmium	2×10^{-7}	0.01 (44)	0.00002
Chromium	4×10^{-7}	0.05 (44)	0.000008
Copper	$<7 \times 10^{-6}$	1.0 (44)	0.000007
Cyanides	7×10^{-7}	0.005 (44)	0.00014
Lead	6×10^{-6}	0.05 (44)	0.00012
Mercury	1×10^{-7}	0.002 (44)	0.00005
Nickel	4×10^{-5}	0.0013 (44)	0.031
Selenium	0.002	0.01 (44)	0.2
Silver	NDL[b]	0.05 (44)	–[c]
Thallium	NDL[b]	0.008 (41, 43)	–[c]
Zinc	7×10^{-5}	5.0 (44)	0.000014

[a] Free silica concentration.

[b] No detectable level.

[c] Not calculated.

TABLE 36. HAZARDOUS AND RUNOFF CONCENTRATION LEVELS FOR WATER QUALITY PARAMETERS FROM COAL STORAGE AREAS

Effluent parameter	Runoff concentration entering waterway, g/m^3	Hazardous concentration, g/m^3	C_R/C_H ratio
Total phosphate	NDL[a]	1×10^{-7}[b]	–[c]
Sulfate	0.04	250 (44)	2×10^{-4}
Nitrate	3×10^{-5}	10 (44)	3×10^{-6}
TDS	0.08	250 (44)	3.2×10^{-4}

[a] No detectable level.

[b] Phosphorus standard.

[c] Not calculated.

TABLE 37. HAZARDOUS AND RUNOFF CONCENTRATION LEVELS FOR ORGANIC POLLUTANTS FROM COAL STORAGE

Effluent	Runoff concentration (C_R), 10^{-6} g/m^3	Hazardous concentration (C_H), g/m^3	C_R/C_H ratio
Acenaphthene	0.02	1,350	1.5×10^{-11}
Benzidene	0.02	0.695	2.9×10^{-8}
Benzo(ghi)perylene	0.07	0.054	1.3×10^{-6}
2-Chloronaphthalene	0.02	4.68	4.3×10^{-9}
Fluoranthene	0.02	4.5	4.4×10^{-9}
Fluorene	0.02	33.8	5.9×10^{-10}

SECTION 5

CONTROL TECHNOLOGY

PRESENT APPLICATIONS OF CONTROL TECHNOLOGY

No methods of water pollution control are presently applied to leachate and runoff from coal stockpiles maintained at coal usage sites. However, present regulations established for effluents from coal storage areas may require control to be used at some facilities. This will require future applications of control technology. For drainage from stockpiles at steam electric plants, collection, neutralization, and settling by gravity are presented as the best practicable control technology currently available (31). Other methods of control currently practiced include: 1) construction of collection ditches around the area, 2) installation of a hard surface over the area to direct drainage to a sump, 3) storage of coal in bins and hoppers with runoff collected in trenches, and 4) establishment of vegetative covers around the stockpile to control erosion and sedimentation (39).

FUTURE APPLICATIONS OF CONTROL TECHNOLOGY

There are two types of control technologies available for pollutants from coal pile drainage; biological, and chemical/physical treatment. Treatment methods applicable to the pollutants included within the scope of this study are discussed below.

Biological Treatment

Biological treatment utilizes biochemical reactions and adsorption characteristics of living microorganisms to reduce BOD, COD, TOC, and TSS levels. The organics are converted to CO_2, NO_3, and NO_2. The life and growth of these microorganisms depend on availability of carbon and nitrogen. Table 38 lists the biological treatment methods applicable to water pollutants from coal stockpiles.

The activated sludge process is a wastewater treatment in which a mixture of sewage and activated sludge is agitated, aerated, and stabilized in a reactor under aerobic conditions. The activated sludge consists of a gelatinous matrix in which filamentous and unicellular bacteria are imbedded and on which protozoa feed

TABLE 38. BIOLOGICAL WATER TREATMENTS FOR COAL STOCKPILE WATER POLLUTANTS

Treatment technique	Pollutant BOD	 COD	 TOC	 TSS	 Nitrate
Aerobic:					
Activated sludge	x	x	x	x	
Trickling filters	x	x	x	x	
Aerated lagoons	x	x	x	x	
Aerated ponds	x	x	x	x	
Activated sludge modifications	x	x	x	x	
Anaerobic:					
Sludge digestion	x	x		x	x
Contact process	x	x		x	x
Aerobic filter	x	x		x	x
Anaerobic ponds	x	x		x	x
Anaerobic-aerobic ponds	x	x	x	x	x

(45). This system has a BOD removal efficiency of 75% to 95% (46). Total removal of organic materials by a typical activated sludge process is from 90% to 95% (45).

Trickling filters are fixed-bed reactors and sedimentation tanks utilizing rocks or plastic media as a growth surface for bacterial slime to effect the biological reactions. The filter functions to remove finely divided, suspended, colloidal and dissolved organics. Removal efficiencies for trickling filters are 60% to 85% for BOD_5, 30% to 70% for COD, and 60% to 85% for TSS (47, 48).

Aerated lagoons are similar to the activated sludge process, but wastewater is treated on a flow-through basis in lagoons. Oxygen is supplied in a lagoon by surface or diffused aeration units to keep the lagoon contents in suspension. The essential function of the lagoon is waste conversion. BOD_5 removal can reach 60% to 70%. Solids are removed in a settling tank, a normal component of most lagoon systems. If the solids are returned to the lagoon, this process is the same as the activated sludge process (46).

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(45) Cheremisinoff, P. N. Biological Wastewater Treatment. Pollution Engineering, September 1976. pp. 32-38.

(46) Metcalf and Eddy, Inc. Wastewater Engineering: Collection, Treatment, and Disposal. McGraw-Hill Book Company, New York, New York, 1972. 782 pp.

(47) Bush, K. E. Refinery Wastewater Treatment and Reuse. Chemical Engineering, 83(8):113, 1976.

(48) Nemerow, N. Y. Liquid Waste of Industry Theories, Practices, and Treatment. Addison-Wesley Publishing Co., Reading, Massachusetts, 1971. 584 pp.

An aerobic pond contains bacteria and algae in suspension, and aerobic conditions prevail throughout its depth. Oxygen enters the pond from algae production and atmospheric diffusion. The pond is mixed periodically with pumps or aerators. The BOD_5 removal efficiency in these ponds can range up to 95%, but it is generally about 50% (45).

Activated sludge modifications are alterations of the activated sludge treatment process. They consist of different flow models, aeration systems, loadings, and applications. Table 39 illustrates the activated sludge modification processes and operational characteristics. Flow models refer to the types of reactors used for biological waste treatment based on their hydraulic flow characteristics (46).

The major application of anaerobic waste treatment is in the digestion of concentrated sewage sludges. However, dilute organic wastes can be treated anaerobically with the anaerobic contact process or anaerobic filter. Anaerobic digestion consists of receiving concentrated sludge in a complete-mix reactor system that uses microorganisms to decompose the organic matter.

High BOD wastes can be handled efficiently by the anaerobic contact process in which raw wastes are mixed with recycled sludge and digested in a mixed digestion chamber. The mixture is then separated with a clarifier or flotation unit, and the supernatant liquid is discharged.

The anaerobic filter is a column filled with various solid media. Waste flows upward through the column in which the anaerobic bacteria grow.

Anaerobic ponds are anaerobic throughout their depth except for a shallow surface zone. Stabilization is brought about by a combination of precipitation and anaerobic conversion of organics. BOD_5 conversion efficiencies of 70% are routine with 85% levels achievable (46).

The anaerobic-aerobic ponds have three zones: 1) an aerobic surface layer to support photosynthetic algae and bacteria, 2) an anaerobic bottom zone that consists of accumulating solids decomposed by anaerobic bacteria, and 3) an intermediate anaerobic-aerobic layer of facultative bacteria decomposing organic wastes.

Physical/Chemical Treatment

The physical/chemical treatment processes possibly applicable to water pollutants from coal stockpiles are listed in Table 40. These processes are discussed below.

TABLE 39. ACTIVATED SLUDGE MODIFICATIONS AND OPERATIONAL CHARACTERISTICS (46)

Process modification	Flow model	Aeration system	BOD removal efficiency, %	Application
Conventional	Plug-flow	Diffused-air, mechanical aerators	85 to 95	Low-strength domestic wastes, susceptible to shock loads.
Complete-mix	Complete-mix	Diffused-air, mechanical aerators	85 to 95	General application, resistant to shock loads, surface aerators.
Step-aeration	Plug-flow	Diffused-air	85 to 95	General application to wide range of wastes.
Modified-aeration	Plug-flow	Diffused-air	60 to 75	Intermediate degree of treatment where cell tissue in the effluent is not objectionable.
Contact-stabilization	Plug-flow	Diffused-air, mechanical aerators	80 to 90	Expansion of existing systems, packaged plants, flexible.
Extended-aeration	Complete-mix	Diffused-air, mechanical aerators	75 to 95	Small communities, package plants, flexible surface aerators.
Kraus process	Plug-flow	Diffused-air	85 to 95	Low-nitrogen, high-strength wastes.
High-rate aeration	Complete-mix	Mechanical aerators	75 to 90	Use with turbine aerators to transfer oxygen and control the floc size, general application.
Pure-oxygen systems	Complete-mix reactors in series	Mechanical aerators	85 to 95	General application, use where limited volume is available, use near economical source of oxygen, turbine or surface aerators.

TABLE 40. PHYSICAL/CHEMICAL TREATMENTS FOR COAL STOCKPILE WATER POLLUTANTS

Treatment techniques	Pollutant																						
	BOD	COD	TOC	TSS	TDS	Phosphate	Sulfate	Acidity	Nitrate	Lead	Nickel	Chromium	Arsenic	Zinc	Mercury	Cadmium	Iron	Calcium	Manganese	General heavy metals	Copper	Chlorides	Cyanide
Coagulation, flocculation, precipitation				x	x	x				x	x	x		x	x	x	x	x	x	x	x		
Carbon adsorption	x	x	x	x		x				x													
Filtration	x	x		x	x	x																	
Sedimentation	x	x		x		x														x			
Chemical oxidation reduction							x										x		x				
Chlorination	x	x					x										x		x			x	x
Ozonation	x	x															x		x				x
Reverse osmosis	x	x			x	x	x		x	x	x	x	x	x		x	x	x	x	x	x	x	
Ion exchange	x	x			x	x	x		x	x	x	x	x	x	x	x	x		x	x	x		
Electrodialysis					x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	
Dissolved air, flotation and foam separation	x	x		x							x	x											
Neutralization								x															
Magnetic separation	x	x		x		x														x			
Wet air combustion	x	x	x																				
Evaporation					x						x	x									x		
Freezing					x																		

Coagulation refers to the reduction of surface charges on suspended colloids and the formation of complex hydrous oxides. Flocculation is the bonding together of the coagulated materials to form settleable or filtrable solids by agglomeration and chemical bridging (49).

Carbon adsorption is generally a tertiary treatment for water treated by normal biological processes. A carbon adsorption column is used to contact wastewater with granular carbon for removal of dissolved organics. Particulate matter may also be removed. Removal efficiencies of carbon adsorption and biological treatment processes applied alone and in tandem are presented in Table 41 (50).

TABLE 41. CARBON ADSORPTION TREATMENT RESULTS (50)

	Removal efficiencies, %		
Pollutant parameter	Biological treatment only	Carbon treatment only	Biocarbon treated
BOD_5	92.8	50.5	96.9
COD	58.1	56.0	88.9
TOC	46.4	75.0	87.5
Chromium	59.1	90.9	90.9
Copper	80.0	94.0	90.0
Iron	-[a]	86.4	59.1
Lead	-[a]	-[a]	-[a]
Zinc	42.9	88.6	78.6
Sulfide	99.4	-[a]	99.4
Cyanides	20	20	20

[a] Treatment not effective.

Filtration is the passing of water through a porous material to separate suspended and colloidal matter. The materials are removed by both physical and chemical actions occurring within the filter bed. Following secondary treatment and addition of coagulants, removal efficiencies are 99% for TSS, 97% for BOD, 85% for COD, 95% for total phosphates, and 10% for TDS (51).

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(49) Culp, R. L., and G. L. Culp. Advanced Wastewater Treatment. Van Nostrand Reinhold Publishing Company, New York, New York, 1971. 310 pp.

(50) Eckenfelder, W. W., P. A. Krenkel, and C. A. Adams. Advanced Wastewater Treatment. American Institute of Chemical Engineers, New York, New York, 1974. 380 pp.

(51) Barnhart, E. L. The Treatment of Chemical Wastes in Aerated Lagoons, Water - 1968. Chemical Engineering Progress Symposium Series, 64(90):111, 1968.

Sedimentation is a process that separates suspended solid materials by gravitational forces. It is applied either as presedimentation, or as sedimentation after coagulation and flocculation or softening. In the latter application, efficiencies of 90% to 95% for TSS, 60% to 80% for COD, 90% for total phosphate, and 90% to 99% for most metals are achievable (52).

Chemical reduction is a process in which the oxidation state is reduced. Nitrate may be reduced using various reducing agents and catalysts. These methods are limited by the cost of the chemicals and the possible creation of toxic wastes due to use of the catalyst (46).

Chemical oxidation is a treatment process in which the oxidation state of a substance is increased. It is used to convert harmful or toxic substances to materials that can be precipitated out of solution, decomposed (or made inert), or converted to less toxic species.

Chlorine is an oxidizing agent used extensively in wastewater treatment, primarily as a disinfectant since its strong oxidizing power kills bacteria. However, it is also used to reduce BOD_5 levels and to prevent slim growths in treatment systems.

Ozone is also a strong oxidizing and disinfecting agent. It is finding wide use in wastewater treatment because it costs less than chlorination. It effectively and economically oxidizes iron and manganese to insoluble forms for filtration (53).

Because of their economics, these oxidation treatments are limited to application to specialized industrial waste treatment and to high level tertiary treatment. Ozone or impoundment oxidation is the primary method used in acid mine drainage treatment processes. Removal of iron by ozonation is accomplished when ferric sulfate is oxidized to ferric sulfite. The sulfite is then completely hydrolyzed to the insoluble hydroxide and precipitated out of solution.

Ozone oxidation of ferrous iron in an acid solution with hydrolysis is shown in Equation 6.

$$FeSO_4 + xH_2O + O_3 \rightarrow Fe(OH)_3 + H_2SO_4 + xH_2O \qquad (6)$$

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(52) Barth, E. F., and J. M. Cohen. Physical/Chemical or Biological, Which Will You Choose? Water and Wastes Engineering, 11(11):20, 1974.

(53) Furgason, R. R., and R. O. Day. Iron and Manganese Removal with Ozone, Part I. Water and Sewage Works, 122(6):42, 1975.

Impoundment oxidation consists of retaining the acidic wastes in a mechanically aerated basin. The reaction is shown in Equation 7.

$$FeSO_4 + O_2 + xH_2O \rightarrow Fe(OH)_3 + H_2SO_4 \qquad (7)$$

The overflow sulfuric acid can then be neutralized prior to entering a stream (54). The acid neutralization is achieved with calcareous shale or limestone according to Equation 8:

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + CO_2 + H_2O \qquad (8)$$

Alkalinity is desirable for reducing the potential acidity due to ferrous sulfate in the drainage. The carbon dioxide plays an important role in producing calcium bicarbonate in the water as shown in Equations 9 and 10.

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \qquad (9)$$

$$H_2CO_3 + CaCO_3 \rightarrow Ca(HCO_3)_2 \qquad (10)$$

However, the solubility and retention of carbon dioxide is adversely affected by aeration. When drainage with calcium bicarbonate is aerated it does not become acidic even though it still carries its original content of ferrous sulfate. The iron and bicarbonate ions become unstable on exposure to the atmosphere and the iron is precipitated. This is expressed, in Equation 11, as:

$$FeSO_4 + Ca(HCO_3)_2 \rightarrow CaSO_4 + Fe(HCO_3)_2 \qquad (11)$$

and the iron is then eliminated by aeration, Equation 12:

$$4Fe(HCO_3)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3\downarrow + 8CO_2\uparrow \qquad (12)$$

Iron is thus eliminated by oxidation and precipitation as ferric hydroxide, and bicarbonate is dissipated by the evolution and loss of carbon dioxide from the drainage into the air (20).

Reverse osmosis is a treatment operation that separates inorganic ions and dissolved and suspended solids in solution. In osmosis, solutions of different concentrations are separated by a semipermeable membrane, and solution flows through the membrane to equalize concentration levels. In reverse osmosis a pressure greater than the osmotic level is exerted, forcing the solvent in the opposite direction and thereby separating the dissolved solids. Efficiency of reverse osmosis in wastewater treatment depends on the rejection characteristics of the membrane. Typical rejection characteristics are shown in Table 42 (55). Reverse osmosis techniques are improving and efficiency is increasing. This process is currently favored over electrodialysis and ion exchange because of its greater efficiency and added removal of organics (56). However, in acid mine drainage applications, the problem of disposing of the acidic wastes exists. Although deep well injection has been utilized for disposal of acid mine wastes, only a limited quantity can be disposed of in this fashion.

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(54) Lorenz, W. C., and R. W. Stephan. A Review of Current Research on Coal Mine Drainage in Appalachia. U.S. Department of the Interior, Bureau of Mines, Pittsburgh, Pennsylvania, 1967. 12 pp.

TABLE 42. TYPICAL MEMBRANE SOLUTE REJECTION IN REVERSE OSMOSIS (55)

Solute	Rejection, %		
	Maximum	Minimum	Average
Calcium, Ca^{2+}	99.7	96.3	>99
Magnesium, Mg^{2+}	99.9	93	>99
Iron, Fe^{2+} and Fe^{3+}	~100	99.9	~100
Manganese, Mn^{2+}	~100	-[a]	~100
Aluminum, Al^{3+}	99.9	97.3	>99
Chromium, Cr^{6+} pH 2.6	-[c]	-[c]	92.6
4.2	-[c]	-[c]	97.2
7.6	-[c]	-[c]	98.6
Sulfate, SO_4^{2-}	~100	99^{+}	>99
Chloride, Cl^-	97	86	-[b]
Nitrate, NO_3^-	86	58	-[b]
Silica (at pH5)	95	80	-[b]
Orthophosphate, PO_4^{3-}	~100	-[a]	>99
Polyphosphate	~100	-[a]	>99
Total dissolved solids (TDS)	99	89	-[b]
COD - secondary effluent	97	94	-[b]
- sulfite liquor	97.5	94.9	-[b]
BOD - secondary effluent	94	81	-[b]
- sulfite liquor	92.2	85.8	-[b]

[a] No minimum; ~100% rejection.

[b] Unknown.

[c] Insufficient data for determining minimum and maximum.

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(55) Weber, W. J. Physicochemical Processes for Water Pollution Control. John Wiley & Sons, Inc., New York, New York, 1972. 596 pp.

(56) Monti, R. P., and P. T. Silbermann. Wastewater System Alternates: What Are They...and What Cost?, Part IV. Water and Wastes Engineering, 11(6):52, 1974.

Ion exchange is a sorption process in which ions attached to an exchange medium are replaced by ions passing through it in solution. The exchange resin is insoluble, and the ion exchange takes place on its surface. There are many factors affecting the efficiency and application of ion exchange. Solids in the effluent should not exceed 400 g/m^3 (56). Generally removal efficiencies are 97% for total phosphate, 90% for nitrates, 100% for sulfates, and 45% for COD (55).

Electrodialysis is a treatment operation that separates solutes on the basis of diffusion rate differences through porous membranes. This process is accelerated by an electrical potential imposed across the membrane. This process is primarily applied in water desalination but is also used for water demineralization. Cost and operating problems are currently limiting its use in wastewater treatment (57).

With dissolved air flotation, a process that removes suspended solids, wastestreams are saturated with pressurized gas. The waste then flows to a retention tank, out through a reducing valve, and into a flotation tank. When pressure is reduced the gas comes out of solution forming bubbles which adhere to the suspended particles. Foam formation occurs naturally or is induced by the addition of chemicals. A sludge collector then removes the surface layer. Removal efficiencies for coagulation and flocculation followed by flotation are, conservatively: 50% to 85% for TSS, 20% to 70% for BOD_5, and 10% to 60% for COD (47).

Neutralization is a chemical process in which equimolar quantities of acid and base react to form salts and water that is chemically neutral. This is accomplished by mixing wastes with bases such as limestone, lime slurry, caustic soda, or soda ash, and alkaline wastes with sulfuric acid. Mineral acidity is neutralized in acid mine drainage with an alkali, usually hydrated lime, which removes iron, manganese, and other soluble metals through the formation of their insoluble hydroxides (34). Total iron reduction is generally representative of the overall effectiveness of the neutralization process. The basic reaction is listed in Equation 13 (54):

$$\text{Ferrous sulfate} + \text{alkali} \rightarrow \text{ferrous hydroxide} + \text{alkali sulfate} \qquad (13)$$

Alkali materials under investigation for acid mine drainage applications include oxides, hydroxides, and carbonates of calcium, sodium, magnesium, manganese, and ammonia. The activity (rate of reaction) is especially high for sodium hydroxide, sodium carbonate (soda ash), and ammonia. These materials are expensive in comparison to limes and limestone. However, lime neutralization imparts a permanent hardness to the treated water (58).

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(57) Young, R. A., P. N. Cheremisinoff, and S. M. Feller. Tertiary Treatment: Advanced Wastewater Techniques. Pollution Engineering, 7(4):26, 1975.

Acid treatment techniques have not been specifically developed for wastes from coal storage areas. Therefore, treatment studies and processes conducted on acid mine drainage (AMD) can be applied to the wastes from coal storage areas. However, the wastes from these areas are less acidic as compared to mine drainage, and there is less volume of waste to treat.

The treatment methods that have been developed and tested for AMD are listed in Table 43.

TABLE 43. ACID MINE DRAINAGE TREATMENT METHODS (58)

Treatment method	Developer
Lime-limestone treatment	U.S. Environmental Protection Agency
Limestone treatment	Bituminous Coal Research Institute
Iron-oxidation-limestone neutralization	Penn State University
Biological-limestone treatment process	Consolidation Coal Company
Biological treatment	Syracuse University
Neutrolysis	U.S. Environmental Protection Agency
Demineralization	Culligan International Company
Foam separation	Horizons, Inc.
Electrochemical oxidation	Tyco Corporation
Partial freezing	Applied Science Labs, Inc.

Treatment costs for these processes normally range between $0.10 and $1.32 per 5,000 liters (1,321 gal) of water, depending on the quality and quantity of water to be treated. Waters containing a high percentage of ferrous iron are difficult or impossible to treat. The least costly treatment system appears to be an iron-oxidation-limestone neutralization process. It is applicable to all kinds of acid waters including those containing large quantities of ferrous iron (58).

Another treatment is magnetic separation, in which a filter matrix is magnetized. As the wastewater passes through it the magnetized materials are trapped. In pilot plant studies, removal efficiencies of 95% for TSS and 92% for BOD_5 were obtained (56).

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(58) Boyer, J. F. Status of Coal Mine Drainage Technology. Coal Mining and Processing, 9(1):56-59, 1972.

Wet air combustion oxidizes organic wastes under high temperature and pressure. It is mainly used in sludge destruction.

Evaporation is used in concentrating liquid wastes. It simply involves boiling off liquid and leaving a concentrated solids fraction that can be disposed of easily. It is generally applicable to materials with negligible vapor pressures (59).

Freezing is the opposite of evaporation and is used mainly for concentrating wastes in salt waters. Waste is cooled until crystallization, then the ice is separated from the waste and washed to remove the brine (60).

CONTROL CONSIDERATIONS

Stockpiling Techniques

The prime control technology consideration for any pollution source is control at the source through process alteration. In acidic runoff from coal stockpiles this involves prevention of the mechanisms of acid formation. Pyritic oxidation only requires a small quantity of air and water. The moisture content of air is sufficient for the stoichiometric reaction. Shielding the coal stockpile to avoid oxidation can be achieved. The following methods have proven satisfactory in practice (18):

- Use of sealed bins or bunkers which provide airtight storage suitable for long-term retention of small quantities of coal.
- Sealing the sides and tops of large, compacted piles with asphalt or tar.
- Underwater storage in concrete pits; these are ideal for preventing deterioration, but expensive.
- Surface storage in piles of compacted layers with sides sloping at 0.17 to 0.26 radian (10° to 15°) and the surface covered with fine coal.
- Compacted layer storage in open pits with airtight sides.

In compacting coal piles, each layer is consolidated with bulldozers as it is laid down. The top of the pile is flattened, and the height is not great. Coal is removed in layers, and the top remaining layer is again smoothed and compacted. Coals of different rank are not stored together.

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(59) Minor, P. S. Organic Chemical Industry's Wastewaters - Environmental Science & Technology, 8(7):620, 1974.

(60) Clark, J. W., W. Viessman, Jr., and M. J. Hammer. Water Supply and Pollution Control, Second Edition. International Textbook Company, Scranton, Pennsylvania, 1971. 661 pp.

Another consideration for effluent reduction is removal of the pyrite from coal. Pyritic sulfur is removed through coal flotation. The resulting clean coal froth is repulped and treated with a coal depressant, a pyrite collector, and a frother to selectively float the remaining pyrite in a second stage. Results on a pilot plant scale produced a 70% and 90% removal of pyrite in two cases (61).

Tough, permeable fabrics can be used under coal stockpile areas as a filter for solids containment in the drainage system. These fabrics stabilize and reinforce the earth while halting erosion.

Design Considerations

Control of effluents from coal pile drainage requires monitoring of site conditions to develop hydrographs (Figure 7) of flow and to determine base flow rates and pollutant concentrations. Anderson and Youngstrom (17) recommended the use of Izzard's method for developing a hydrograph. In this method, the coal pile configuration is defined and the pile is segmented into component strips of unit width with constant slopes and distances of overland flow to a collection point. This permits integration of the "flush phenomenon" into equal time intervals. Each time will be greater than the frequency of the monitoring data, which enables integration of the flow hydrograph to determine volume of coal pile drainage. The average concentration is determined for each time interval, and the mass of pollutant emitted is then the product of this concentration and the volume of pile drainage. This procedure enables a mass-volume relationship to be determined at any time for a treatment system. This relationship is termed the design volume mass curve.

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(61) Miller, K. J. Flotation of Pyrite from Coal: Pilot Plant Study. RI 7822, U.S. Department of the Interior, Bureau of Mines, Pittsburgh, Pennsylvania, 1973. 15 pp.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

STORAGE GROWTH PATTERNS

Past quantities of coal maintained in stock by various coal users are shown in Table 44 and illustrated in Figure 9 (4, 62). In 1940 electric utilities accounted for 20% of the coal stockpiled in the United States. By 1975 utilities stored 85% of the coal inventories. During this period the stockpile quantities of the other coal users dropped from a high of 62% of the coal inventory in 1940 to a low of 8% in 1975. These inventory shifts reflect the coal consumption trends of these users. The growth rate of coal stored was 5,380 metric tons/yr (5,926 tons/yr). For the preceding 5 years (1965-1970), coal stockpile quantities had grown at 930 metric tons/yr (1,025 tons/yr). However, when compared to the consumption of coal during these periods, Figure 10 illustrates that coal storage amounted to 20%, 17%, and 20% of the consumption levels in 1960, 1970, and 1975, respectively (7, (62). Thus, coal storage closely and consistently follows the consumption quantities. It was therefore reasonable to use consumption data in Section 3 to estimate storage quantities.

TABLE 44. PAST YEARLY STOCKS OF COAL PER USER (4, 62)[a]
[10^6 metric tons(10^6 tons)]

Year	Electric utilities	Coke plants	Others[b]	Total
1940	8.3(9.0)	7.2(7.9)	24.9(27)	40.4(44.5)
1950	16.1(17.7)	9.0(9.9)	15.8(17.4)	40.9(45.1)
1960	45.4(50)	10.4(11.5)	13.2(14.6)	69.1(76.2)
1970	55.0(60.6)	8.1(8.9)	9.9(10.9)	73.0(80.5)
1975	84.9(93.6)	7.5(8.3)	7.5(8.3)	99.9(110)

[a] Excludes preparation plants and anthracite storage.

[b] Railroads, steel and rolling mills, cement mills, other manufacturing and mining industries, and retail dealers.

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(62) Bituminous Coal Data, 1970 Edition (21st Edition). National Coal Association, Washington, D.C., 1970. pp. 73-80.

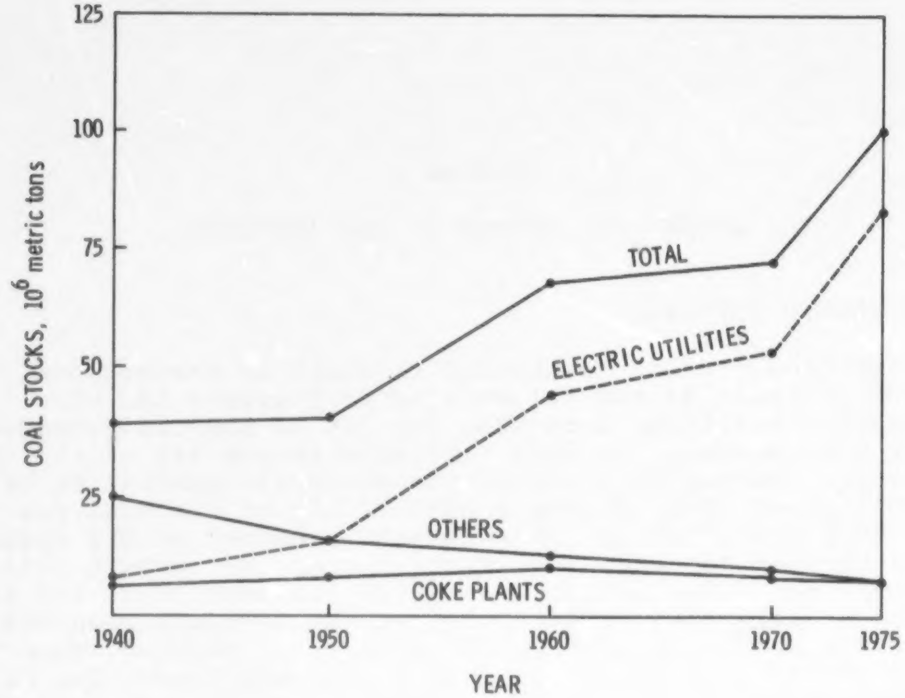

Figure 9. Past yearly stocks of coal, 1940 to 1975 (4, 62).

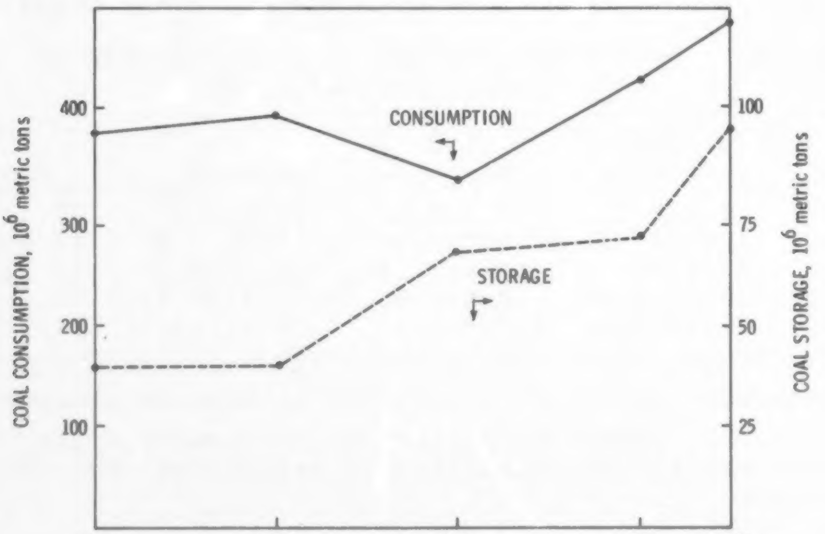

Figure 10. Coal storage and consumption, 1940 to 1975 (7, 62).

The projections for U.S. use of coal as an energy source by the years 1985 and 2000 are 907 x 10^6 metric tons (999 x 10^6 tons) and 816 x 10^6 to 2,721 x 10^6 metric tons (899 x 10^6 to 2,999 x 10^6 tons), respectively (63). Coal storage quantities will increase to approximately 227 x 10^6 metric tons (250 x 10^6 tons) in 1985 and from 204 x 10^6 to 680 x 10^6 metric tons (225 x 10^6 to 750 x 10^6 tons) in 2000.

MINING TRENDS

Total coal reserves in the United States have been estimated at 1.6 x 10^{12} metric tons (1,763 x 10^9 tons). The amount of coal in place as of 1 January 1974 by coal rank is shown in Table 45 (64). Over 50% of this reserve is low rank subbituminous and lignite coal. The amount of low rank coal that can be economically mined is approximately 172 x 10^9 metric tons (18.9 x 10^{10} tons). Over 90% of this coal is located in the Great Northern Plains and Rocky Mountain areas. The current energy situation and need to control sulfur oxide emissions has greatly increased the present and planned use of these coals.

TABLE 45. COAL RESOURCES OF THE UNITED STATES BY RANK, 1974 (64)

	Resources		
Coal rank	10^9 metric tons	10^{10} tons	Percent of total
Anthracite	18.1	2.0	1.2
Bituminous	677.7	74.7	43.1
Subbituminous	440.9	48.6	28.1
Lignite	433.6	47.8	27.6
TOTALS	1,570.2	173.1	100

The present production of low rank coals is 68 x 10^6 metric tons/yr (75 x 10^6 tons/yr). By 1985 greater demand for power production is expected to increase the output of low rank coal to 272 x 10^6 metric tons/yr (300 x 10^6 tons/yr) (64). Future coals stored will tend to be low rank from the Western and Great Northern Plains regions.

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(63) Falkie, T. V. Coal production & consumption in 1985. Coal Mining and Processing, 13(1):51 and 76, 1976.

(64) Grouhovd, G. H., and E. A. Sordreal. Technology and Use of Low-Rank Coals in the U.S.A. In: Seminar on Technologies for the Utilization of Low Calorie Fuels, Varna, Bulgaria, April 20-22, 1976. pp. 40.

The demonstrated coal reserve base of the Western United States is shown in Table 46 (65).

TABLE 46. WESTERN U.S. COAL RESERVES (65)

State	Coal reserves 10^6 metric tons	Coal reserves 10^6 tons	Percent of Western total
Arizona	317	349	<0.01
California	-[a]	-[a]	-[a]
Colorado	13,489	14,838	19
Idaho	-[a]	-[a]	-[a]
New Mexico	3,986	4,385	6
Utah	3,667	4,034	5
Washington	1,773	1,950	3
Wyoming	46,473	51,120	67
TOTALS	69,705	76,676	100

[a] Negligible quantities.

Wyoming represents two-thirds of the potentially minable coal of the Western states. In the Great Northern Plains, Montana represents a reserve of 97,728 x 10^6 metric tons (107 x 10^9 tons) of potentially minable coal, which is over twice the coal reserve base of Wyoming (65).

The total Western and Great Northern Plains deposits have been estimated at 170,550 x 10^6 metric tons (188 x 10^9 tons). Much of this coal lies in beds less than 300 m (984 ft) deep and is attractive for mining on an economic basis. At the present U.S. consumption rate of 509 x 10^6 metric tons/yr (560 x 10^6 tons/yr), these coal reserves alone represent a 300-yr supply (66).

According to the recently appointed Secretary of Energy, the United States has enough coal for 400 years, but some experts put the figure at 50 to 90 years. The new energy package will compel power plants using natural gas to switch to coal. The energy plan may allow relaxation of antipollution laws to speed up the transition to coal (67).

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(65) Ctvrtnicek, T. E., S. J. Rusek, and C. W. Sandy. Evaluation of Low-Sulfur Western Coal Characteristics, Utilization, and Combustion Experience. EPA-650/2-75-046, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1975. 570 pp.

(66) Environmental Impact of Future Energy Sources. Chemical Engineering/Deskbook Issue, 21 October 1974. p. 48.

(67) Superbrains' Superproblem. Time Magazine, 107(4):58-67, 1977.

Most of the coal used in the future will come from the Western states. Transportation will therefore become a big factor. If used for coal transport, slurry pipelines will create vast amounts of effluent water with pollutant concentration similar to those obtained in this coal drainage and runoff study. However, water shortages in the West may preclude slurry pipeline transport.

STOCKPILING TRENDS

Legislation has been proposed that would require utilities to maintain a constant 90-day stockpile of coal. Another proposal would require maintenance of a national coal stockpile equivalent to 6 months' consumption. Passage of this legislation would increase both the size of future stockpiles of coal and the mass pollutants from coal storage as a source of emissions (68).

Utilities will tend to build new facilities near mines, water supplies, and on large plots of land. Coal storage piles will thus be located in areas of lower population and will be farther from local communities. With more land available, future coal piles can be expected to be larger to meet the growing energy needs of the country. Coke plants and industrial boiler facilities are expected to follow the general trends of the utilities because they face similar energy situations and propose similar solutions.

Coal will continue to be stored outdoors to facilitate the loading and/or unloading operations. Outdoor storage inhibits spontaneous combustion by dissipating the heat generated by the oxidation of the coal. However, coal is coated in some regions to prevent the oxidation and resultant spontaneous combustion. This is particularly true in areas of warm climates and low wind speeds.

Coal will therefore continue to be exposed to all meteorological conditions, including precipitation which results in leachate and runoff.

As coal production increases, the number of coal stockpiles and the amount stored and consumed will increase. Coal consumption is anticipated to increase by 7% per year over the next 10 years (69). Coal inventory (days of supply) is expected to increase by 3.8% per year. This will result in a corresponding increase in mass effluent levels.

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(68) Lethi, M. T., J. Elliott, and E. P. Krajeski. Analysis of Steam Coal Sales and Purchases. FEA/G-75/348, Federal Energy Administration, Washington, D.C., April 1975. 139 pp.

(69) Rieber, M., and R. Halcrow. U.S. Energy and Fuel Demand to 1985. CAC No. 108R, National Science Foundation, Washington, D.C., May 1974. 44 pp.

REFERENCES

1. Magee, E. M., H. J. Hall, and G. M. Varga, Jr. Potential Pollutants in Fossil Fuels. EPA-R2-73-249, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1973. 151 pp.

2. A.S.T.M. Standards on Coal and Coke. American Society for Testing and Materials, Philadelphia, Pennsylvania, September 1948. pp. 80.

3. Minerals Yearbook, 1973, Volume I. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1973. pp. 8-36.

4. Bituminous Coal and Lignite Distribution, Calendar Year 1975 (Bituminous Coal and Lignite Distribution Quarterly). Mineral Industry Surveys, U.S. Department of the Interior, Washington, D.C., 12 April 1976. 51 pp.

5. Shipley, D. F. Coal Storage. Monthly Bulletin of the British Coal Utilisation Research Association, XXIII(11-Part II):433-446, 1959.

6. Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio. (Final document submitted to the EPA by Monsanto Research Corporation, July 1977.) 96 pp.

7. Production of Coal - Bituminous and Lignite, 1976, Per Week. Weekly Coal Report No. 3060, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 7 May 1976. 4 pp.

8. FPC Issues Electric Fuel Consumption, Stocks. News Release No. 20499, Federal Power Commission, Washington, D.C., 22 July 1974. 3 pp.

9. Coke and Coal Chemicals in August 1976. Coke and Coal Chemicals Monthly, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., August 1976. 2 pp.

10. Keystone Coal Manual, 1973. McGraw-Hill Publications, New York, New York, 1973. pp. 304-410.

11. Electric Utility Statistics. Public Power, 32:28-84, January-February, 1974.

12. Steam-Electric Plant Factors/1973 Edition. National Coal Association, Economics and Statistics Division, Washington, D.C., December 1973. 110 pp.

13. Coke Producers in the United States in 1972. Mineral Industry Surveys, U.S. Department of the Interior, Washington, D.C., 27 November 1973. pp. 2-5.

14. Minerals Yearbook, 1972, Volume II. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1972. p. 372.

15. Selvig, W. A., and F. H. Gibson. Analysis of Ash from U.S. Coals. Bureau or Mines Bulletin 567, U.S. Department of the Interior, Washington, D.C., 1956. 33 pp.

16. Mineral Matter and Trace Elements in U.S. Coals. Office of Coal Research R&D Report No. 61, Interim Report No. 2, U.S. Department of the Interior, Washington, D.C., 1972. p. 63.

17. Anderson, W. C., and M. P. Youngstrom. Coal Pile Leachate Quantity and Quality Characteristics. Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers, 102(EE6):1239-1253, 1976.

18. Kirk-Othmer Encylopedia of Chemical Technology, Second Edition, Volume 5. John Wiley & Sons, Inc., New York, New York, 1967. pp. 606-678.

19. Morth, A. H., E. E. Smith, and K. S. Shumate. Pyritic Systems: A Mathematical Model. EPA-R2-72-002, U.S. Environmental Protection Agency, Washington, D.C., November 1972. 171 pp.

20. The Incidence and Formation of Mine Drainage Pollution in Appalachia. Appalachian Regional Commission, Washington, D.C., June 1969. 464 pp.

21. Handbook of Applied Hydrology. Ven te Chow, ed. McGraw-Hill Book Co., New York, New York, 1964. pp. 14-1 through 14-54.

22. Geraghty, J. J., D. W. Miller, F. Van der Leeden, and F. Y. Troise. Water Atlas of the United States. Water Information Center, Inc., Port Washington, New York, 1973. Plate 21.

23. Development Document for Proposed Effluent Limitation Guidelines and New Source Performance Standards for the Steam Electric Power Generating Point Source Category. EPA-440/1-73-029, U.S. Environmental Protection Agency, Washington, D.C., March 1974. pp. 128-130.

24. Hall, D. A. The Storage of Coal. Coke and Gas, December 1956. pp. 498-504.

25. Lorenz, W. C., and R. W. Stephan. The Oxidation of Pyrite Associated with Coal Mines. U.S. Department of the Interior, Bureau of Mines, Pittsburgh, Pennsylvania, 1967. 21 pp.

26. Lorenz, W. C., and R. W. Stephan. Factors that Affect the Formation of Coal Mine Drainage Pollution in Appalachia. U.S. Department of the Interior, Bureau of Mines, Pittsburgh, Pennsylvania, 1967. 17 pp.

27. Sampling and Analysis Procedures for Survey of Industrial Effluents for Priority Pollutants. U.S. Environmental Protection Agency, Cincinnati, Ohio, March 1977. 180 pp.

28. Hamersma, J. W., S. L. Reynolds, and R. F. Maddalone. IERL-RTP Procedures Manual: Level 1 Environmental Assessment. EPA-600/2-76-160a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1976. pp 60-64.

29. Standard Methods for the Examination of Water and Wastewater, 14th Edition. M. A. Franson, ed. American Public Health Association, Washington, D.C., 1976. 1193 pp.

30. Annual Report of Research and Technologic Work on Coal. IC 7518, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1949. 39 pp.

31. Methods for Identifying [illegible] Evaluating the Nature and Extent of Non-Point Sources of Pollutants. EPA-430/9-73-014, U.S. Environmental Protection Agency, Washington, D.C., October 1973. 261 pp.

32. The World Almanac and Book of Facts, 1976. G. E. Delury, ed. Newspaper Enterprise Association, New York, New York, 1975. pp. 790.

33. Handbook of Water Resources and Pollution Control. H. W. Gehm and J. I. Bregman, eds. Van Nostrand Reinhold Co., New York, New York, 1976. pp. 444-447.

34. Part IV: Environmental Protection Agency - Coal Mining Point Source Category - Interim Final Rules. Federal Register, 40(202):48830-48840, 1975.

35. Chapter 1 - Environmental Protection Agency - Part 434 - Coal Mining Point Source Category - Effluent Guidelines and Standards. Federal Register, 41(94):19832-19843, 1976.

36. Environmental Protection Agency - Coal Mining Point Source Category - Effluent Guidelines and Standards. Federal Register, 42(80):21379, 1977.

37. Calendar of EPA Regulations Under Consideration. Pollution Engineering, Yearbook and Product Reference Guide, 28 February 1977. pp. 16-18.

38. Development Document for Interim Final Effluent Limitations Guidelines and New Source Performance Standards for the Coal Mining Point Source Category. EPA 440/1-76/057-a. U.S. Environmental Protection Agency, Washington, D.C., May 1976 pp. 95-96.

39. Environmental Protection Agency - Part 423 - Steam Electric Power Generating Point Source Category - Effluent Guidelines and Standards. Federal Register, 39(196):36206-36207, 1974.

40. Walden, C. C., and T. E. Howard. Toxicity: Research and Regulation. In: Proceedings of 1976 TAPPI Environmental Conference, Atlanta, Georgia, April 26-28, 1976. pp. 93-99.

41. Handy, R. W., and M. Samfield. Estimation of Permissible Concentrations of Pollutants for Continuous Exposure; Part II: Permissible Water Concentrations. Contract 68-02-1325, Task 34, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1975. 76 pp.

42. TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1975. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1975. 97 pp.

43. The Toxic Substances List - 1974. HSM 99-73-45, National Institute for Occupational Safety and Health, Rockville, Maryland, June 1974. 904 pp.

44. Quality Criteria for Water. EPA-440/9-76-023, U.S. Environmental Protection Agency, Washington, D.C., July 1976. 501 pp.

45. Cheremisinoff, P. N. Biological Wastewater Treatment. Pollution Engineering, September 1976. pp. 32-38.

46. Metcalf & Eddy, Inc. Wastewater Engineering: Collection, Treatment, and Disposal. McGraw-Hill Book Company, New York, New York, 1972. 782 pp.

47. Bush, K. E. Refinery Wastewater Treatment and Reuse. Chemical Engineering, 83(8):113, 1976.

48. Nemerow, N. Y. Liquid Waste of Industry Theories, Practices, and Treatment. Addison-Wesley Publishing Co., Reading, Massachusetts, 1971. 584 pp.

49. Culp, R. L., and G. L. Culp. Advanced Wastewater Treatment. Van Nostrand Reinhold Publishing Company, New York, New, York, 1971. 310 pp.

50. Eckenfelder, W. W., P. A. Krenkel, and C. A. Adams. Advanced Wastewater Treatment. American Institute of Chemical Engineers, New York, New York, 1974. 380 pp.

51. Barnhart, E. L. The Treatment of Chemical Wastes in Aerated Lagoons, Water - 1968. Chemical Engineering Progress Symposium Series, 64(90):111, 1968.

52. Barth, E. F., and J. M. Cohen. Physical/Chemical or Biological, Which Will You Choose? Water and Wastes Engineering, 11(11):20, 1974.

53. Furgason, R. R., and R. O. Day. Iron and Manganese Removal with Ozone, Part I. Water and Sewage Works, 122(6):42, 1975.

54. Lorenz, W. C., and R. W. Stephan. A Review of Current Research on Coal Mine Drainage in Appalachia. U.S. Department of the Interior, Bureau of Mines, Pittsburgh, Pennsylvania, 1967. 12 pp.

55. Weber, W. J. Physicochemical Processes for Water Pollution Control. John Wiley & Sons, Inc., New York, New York, 1972. 596 pp.

56. Monti, R. P., and P. T. Silbermann. Wastewater System Alternates: What Are They....and What Cost?, Part IV. Water and Wastes Engineering, 11(6):52, 1974.

57. Young, R. A., P. N. Cheremisinoff, and S. M. Feller. Tertiary Treatment: Advanced Wastewater Techniques. Pollution Engineering, 7(4):26, 1975.

58. Boyer, J. F. Status of Coal Mine Drainage Technology. Coal Mining and Processing, 9(1):56-59, 1972.

59. Minor, P. S. Organic Chemical Industry's Wastewaters - Environmental Science & Technology, 8(7):620, 1974.

60. Clark, J. W., W. Viessman, Jr., and M. J. Hammer. Water Supply and Pollution Control, Second Edition. International Textbook Company, Scranton, Pennsylvania, 1971. 661 pp.

61. Miller, K. J. Flotation of Pyrite from Coal: Pilot Plant Study. RI 7822, U.S. Department of the Interior, Bureau of Mines, Pittsburgh, Pennsylvania, 1973. 15 pp.

62. Bituminous Coal Data, 1970 Edition (21st Edition). National Coal Association, Washington, D.C., 1970. pp. 73-80.

63. Falkie, T. V. Coal production & consumption in 1985. Coal Mining and Processing, 13(1):51 and 76, 1976.

64. Grouhovd, G. H., and E. A. Sordreal. Technology and Use of Low-Rank Coals in the U.S.A. In: Seminar on Technologies for the Utilization of Low Calorie Fuels, Varna, Bulgaria, April 20-22, 1976. pp. 40.

65. Ctvrtnicek, T. E., S. J. Rusek, and C. W. Sandy. Evaluation of Low-Sulfur Western Coal Characteristics, Utilization, and Combustion Experience. EPA-650/2-75-046, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1975. 570 pp.

66. Environmental Impact of Fugure Energy Sources. Chemical Engineering/Deskbook Issue, 21 October 1974. pp. 48.

67. Superbrains' Superproblem. Time Magazine, 107(4):58-67, 1977.

68. Lethi, M. T., J. Elliott, and E. P. Krajeski. Analysis of Steam Coal Sales and Purchases. FEA/G-75/348, Federal Energy Administration, Washington, D.C., April 1975. 139 pp.

69. Rieber, M., and R. Halcrow. U.S. Energy and Fuel Demand to 1985. CAC No. 108R, National Science Foundation, Washington, D.C., May 1974. 44 pp.

APPENDIX A

COAL USAGE AND STORAGE STATISTICS

Bituminous and lignite coal usage and storage quantities per state and per user site are listed in Table A-1. Anthracite usage per user site is listed in Table A-2. The distribution of anthracite, computed proportionally from the 1972 distribution data, is presented in Table A-3. The storage of anthracite per state is computed from a usage-weighted ratio (Ds/Do) of 0.18, from Table A-2.

At preparation plants a 10-day supply of coal is estimated to exist. In addition, it is assumed that these plants operate 250 days per year. Using the weighted ratio of 0.04 for (Ds/Do), the storage quantities per preparation plant per state of Table A-4 are obtained.

The total amount of coal stored per state is thus the sum of each state's values in Tables A-1, A-3, and A-4. Total values are presented in the text in Table 4.

TABLE A-1. BITUMINOUS AND LIGNITE USAGE AND STORAGE PER USER SITE, PER STATE, 1975 (4) (10^3 tons)

State	Usage Electric utilities	 Coke plants	Others[a]	Storage
Alabama	19,246	6,783	2,176	5,884
Alaska	257		511	98
Arizona	3,873		112	922
Arkansas			34	6
California		1,861	225	320
Colorado	6,431	1,085	694	1,785
Connecticut			24	4
Delaware	972		22	230
Florida	5,451		18	1,273
Georgia	14,619		399	3,476
Hawaii				
Idaho			511	92
Illinois	34,853	3,094	4,001	9,301
Indiana	28,715	14,072	4,141	9,543
Iowa	5,560		1,181	1,507
Kansas	3,220		113	770
Kentucky	25,724	1,241	1,515	6,375
Louisiana				
Maine			29	5
Maryland	3,979	3,574	308	1,507
Massachusetts	288		102	85
Michigan	21,802	5,343	4,145	6,562
Minnesota	8,782	957	1,294	2,396
Mississippi	1,573		20	365
Missouri	17,858	278	1,605	4,438
Montana	1,203		51	286
Nebraska	1,468		265	385
Nevada	4,444		68	1,034
New Hampshire	1,054		4	243
New Jersey	1,367	14	137	341
New Mexico	7,422			1,707
New York	6,155	3,491	2,198	2,335
North Carolina	19,825		1,490	4,828
North Dakota	5,069		581	1,285
Ohio	12,528		9,079	4,552
Oklahoma			19	3
Oregon			107	19
Pennsylvania	35,778	22,796	4,815	12,618
Rhode Island			1	
South Carolina	4,497		1,154	1,255
South Dakota	2,134		66	509

(continued)

TABLE A-1 (continued).

State	Usage Electric utilities	 Coke plants	Others[a]	Storage
Tennessee	24,659	170	1,804	6,093
Texas	9,070	975	2,325	2,677
Utah	1,996		547	563
Vermont	8		2	2
Virginia	3,987		2,574	1,392
Washington	3,718		403	938
West Virginia	26,336	4,481	3,543	7,443
Wisconsin	11,598	253	2,224	3,139
Wyoming	7,283		572	1,799
TOTALS	394,802	70,468	57,209	112,390

[a] Except preparation plants.

Note.—Blank areas indicate no coal used.

TABLE A-2. ANTHRACITE USAGE, 1975[a]

User	Days of operation (Do)	Days of supply (Ds)	Usage, 10^3 tons
Electric utilities	365	85	1,482
Residential and commercial heating	365	60	2,128
Colliery[b]	250	10	10
Sintering and pelletizing	250	40	237
Other uses	250	44	925

[a] Personal communication with Ms. Williams, U.S. Bureau of Mines, Division of Fossil Fuels, 6 December 1976.

[b] Assumed values.

TABLE A-3. DISTRIBUTION OF ANTHRACITE USAGE PER STATE[a]
(10^3 tons)

State	Usage	Storage
Delaware	14	3
Illinois	38	7
Indiana	33	6
Iowa	24	4
Maryland	19	3
Michigan	38	7
Minnesota	10	2
Missouri	24	4
New Jersey	143	26
New York	588	106
Ohio	100	18
Pennsylvania	3,433	618
Virginia	5	1
Wisconsin	10	2
Other states	253	46
TOTALS	4,732	853

[a] Personal communication with Ms. Williams, U.S. Bureau of Mines, Division of Fossil Fuels, 6 December 1976.

TABLE A-4. GEOGRAPHICAL DISTRIBUTION OF COAL PRODUCTION AT PREPARATION PLANTS, 1972

State	Total production, 10^3 tons	Number of plants	Stockpiled quantity, 10^3 tons
Alabama	20,814	20	832
Alaska	668	1	27
Colorado	5,522	3	221
Illinois	65,523	38	2,621
Indiana	25,949	11	1,038
Kentucky	121,187	50	4,847
Ohio	50,967	21	2,039
Oklahoma	2,624	6	105
Pennsylvania	75,939	71	3,037
Tennessee	11,260	2	450
Utah	4,802	7	192
Virginia	34,028	31	1,361
Washington	2,634	2	105
West Virginia	123,743	136	4,950
Other states[a]	49,725	9	1,989
TOTAL			23,814

[a] Arizona, Arkansas, Iowa, Kansas, Maryland, Missouri, Montana, New Mexico, North Dakota, Texas, and Wyoming.

APPENDIX B

RAINFALL SIMULATOR

Drainage from coal stockpiles was studied using the rainfall simulator arrangement shown in Figure 3 in the text. Use of this unit allowed a number of coals from various regions to be studied at minimum cost and time. The simulator enabled the control of otherwise uncontrollable factors such as rainfall intensity, duration, and frequency. In addition, interferences with sampling were avoided.

The simulator consists of a tank, pump, and valve assembly which feeds water to a manifold. Water proceeds through piping, electric valves, and nozzle arrangements into an array of modules suspended in the air on a frame above a platform.

The 0.189-m^3 (50-gal) plastic tank was cleaned prior to each run. The centrifugal cast iron pump was bolted directly to the tank. Cast iron was used because a pressure of 158.6 kPa (23 psi) was required to operate the nozzles and achieve the pressure load necessary to reach the modules. Pump pressure was controlled by an in-line valve and a bypass valve which fed back into the tank. Valves were constructed of brass. The pump and valves were flushed prior to each run to remove any metal contamination. The pump and valve arrangement was connected to a manifold with rubber hosing.

The plastic manifold was connected to four piping branches through electric valves which were shut on-off at the contact panel. In this manner, the flow rate to each module was established, since each piping branch connected to a manifold which led piping to each module. A schematic of the piping arrangement is shown in Figure B-1.

Each module was 0.37 m^2 (2 ft^2) and about 25 mm (1 in.) high. They were completely enclosed and constructed of plastic. The top of each module was fed by four nozzles connected by rubber hosing to the piping (Figure B-1). From the bottom of each module extended 400 24 mm (1-in.) pieces of plastic surgical tubing. Water flowed through the tubing and exited as a droplet, under the nozzle pressure. Each nozzle operated at 69 kPa (10 psi), and a vacuum was drawn on each module to equalize pressures.

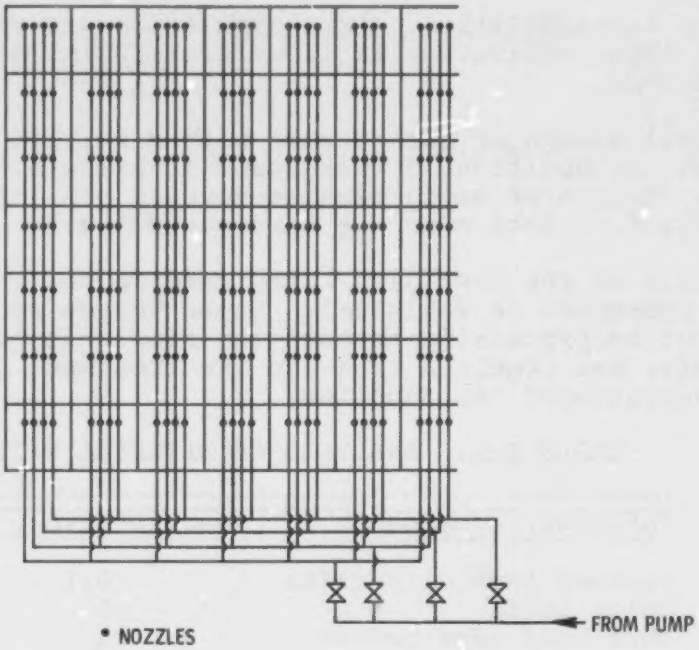

Figure B-1. Piping arrangement of rainfall simulator, top view.

The coal samples were placed in plastic-covered metal pans on a wooden frame structure as shown in Figure 3. A rain gage was attached to the sides of the supporting structure. The rainfall intensity of this unit is normally altered by switches at a remote control panel calibrated to the entire module array. However, it was not necessary to use all the modules of Figure Bl to rain upon the coal. Therefore, to minimize the distilled water requirement, a number of the modules were closed off by plugging the rubber tubing leading to them. The old system had an area of 18.2 m^2 (196 ft^2) which at 13 mm/hr (1/2 in./hr) of rain would have required 0.22 m^2/hr (58.6 gal/hr). With the adjusted system the module area was 3 m^2 (32 ft^2), requiring 0.038 m^3/hr (10 gal/hr) for 13 mm/hr (1/2 in./hr) of rain.

Within the bottom of each coal pan were four specially constructed Teflon® drains which were flush with the bottom of the pan with their ends protruding through the pan and connected to 6.4 mm (1/4 in.) Tygon® tubing. A plastic screen supported by rubber stoppers was placed above the drains to keep the coal from clogging the drains. A 9.1-kg (20-lb) sample of coal was then placed within each pair.

The drains connected with the tubing into HNO_3/H_2SO_4-cleaned and distilled-water-rinsed 0.0019 m^3 (1/2 gal) glass jars. The jars were placed beneath the pans to keep rainfall from diluting the samples. In addition, each jar top was protected with saran wrap to further avoid dilution. Each simulation was run until a volume of drainage equivalent to 13 mm/hr (1/2 in./hr) of rainfall was collected.

The rainfall simulator was flushed with distilled water prior to every run. In addition, a background sample was collected during each run, through an empty plastic-covered pan. This sample was then analyzed to determine the background levels.

The analysis of the distilled water used in the rainfall simulator is presented in Table B-1. These values represent the level prior to processing through the simulation apparatus. Distilled water was required to avoid the treatment chemicals present in conventional tap supplies.

TABLE B-1. ANALYSIS OF RAINFALL WATER

Parameter/component	Concentration, g/m^3
Jackson turbidity units	<0.1
Color units	<5
Threshold odor number	<1
Arsenic	<0.01
Barium	<0.1
Cadmium	<0.001
Chloride	<0.1
Chromium	<0.001
Copper	0.035
Cyanide	<0.01
Iron	<0.001
Lead	<0.013
Manganese	<0.001
Nitrate	<0.1
Phenols	<0.001
Selenium	0.01
Silver	<0.001
Sulfate	<1.0
Total dissolved solids	<1.0
Zinc	0.002
Fluoride	<0.01

Samples collected in the battles were refrigerated and transported immediately for analysis. The pH was measured in the field and all analyses were conducted using standard methods for the examination of water and wastewater (29). The organic materials were analyzed using a gas chromatograph mass spectrometer.

APPENDIX C

SAMPLING RESULTS

Fresh, aged, and aged and moistened coal samples from six coal regions were placed under the rainfall simulator. A background sample was also obtained of each simulated rainfall. Analyzing fresh, aged, and aged and moistened coal enabled observation of effluent concentration deviation with these factors. This deviation versus time reflects the variation for all coal regions. The deviation of average effluent concentration within a single coal region was observed with an Interior Western coal. Both a fresh and an aged coal were obtained from the same mine in this region.

Representative coal samples from seven states (two samples from Appalachia) were obtained fresh from the mines. The eighth coal sample was the aged Interior Western coal mentioned above. Three simulation runs were undertaken. The first run was used to observe the effluent concentration levels from coals unexposed to rainfall for at least 30 days. A second run was performed on an aged and a fresh coal after they remained moist following rainfall the previous day. The third run followed 15 days without rainfall. The coals studied and their sample labels are listed in Table C-1. These runs provide the conditions and sample population necessary for obtaining average effluent concentrations. A background sample from each run was also analyzed for all the effluents under study.

TABLE C-1. COAL SAMPLES STUDIED UNDER RAINFALL SIMULATOR

		Sample labels per simulation run		
Coal region	State	Run 1	Run 2	Run 3
Appalachian	Alabama	D1		D3
	Eastern Kentucky	C1	C2	C3a, C3b, C3c
Great Northern Plains	Montana	A1		A3
Western	Wyoming	E1		E3
Interior Western	Missouri	H1		H3
	Missouri (weathered)	F1	F2	F3
Interior Eastern	Illinois	G1		G3
Southwestern	New Mexico	B1		B3
Background		BK1	BK2	BK3

The results of the analysis performed for each labeled coal sample (Table C-1) for runs 1, 2, and 3 are presented in Tables C-2, C-3, and C-4, respectively. The detection limits for those inorganic materials listed in these tables as not detected (i.e., NDL) are as follows:

Material	Detection limit
Total phosphate as P, g/m^3	0.03
Beryllium, mg/m^3	2
Cadmium, mg/m^3	0.6
Chromium, mg/m^3	10
Silver, mg/m^3	3
Thallium, mg/m^3	100
Mercury, mg/m^3	0.01
Cyanide, g/m^3	0.02

TABLE C-2. COAL STORAGE AREA EFFLUENT CONCENTRATIONS, RUN 1

Effluent parameter	Units	Montana coal A1	New Mexico coal B1	Kentucky coal C1	Alabama coal D1	Wyoming coal E1	Missouri weathered coal F1	Illinois coal G1	Missouri fresh coal H1	Background BK1
Total suspended solids	g/m^3		2,608	736	376	3,384	1,668	564	276	12
Total dissolved solids	g/m^3	316	472	272	140	356	16,444	1,356	504	72
Sulfate	g/m^3	2,960	275	95	58	360	14,500	800	650	28
Iron	mg/m^3	600	2,900	750	750	1,500	3,100,000	1,000	40,000	350
Manganese	mg/m^3	160	70	10	15	480	55,000	270	840	20
Free silica	g/m^3	3.65	<0.05	<2.46	1.51	<0.05	433	4.78	1.7	6.5
Cyanide	mg/m^3	NDL[a]	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL
BOD_5	g/m^3	<20	<20	<10	<10	<10	<5	<5	<10	<5
COD	g/m^3	909	1,137	596	580	2,211	1,100	694	149	8
Nitrate as N	g/m^3	0.24	0.14	0.15	0.06	3.45	0.06	0.44	0.08	0.11
Total phosphate as P	g/m^3	0.06	NDL	NDL	NDL	NDL	NDL	0.06	NDL	0.08
Antimony	g/m^3	<1	14	<1	1	29	12	16	4.4	<1
Arsenic	g/m^3	8.9	13.4	146	<10.3	16.4	31	13.4	19.4	5.2
Beryllium	mg/m^3	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL
Cadmium	mg/m^3	NDL	NDL	NDL	NDL	NDL	875	NDL	NDL	NDL
Chromium	mg/m^3	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL
Copper	mg/m^3	30	50	10	50	30	6,750	35	65	80
Lead	mg/m^3	75	85	80	10	75	530	65	260	<10
Nickel	mg/m^3	10	55	65	5	40	33,200	60	1,480	<10
Selenium	g/m^3	<3	46	83	<3	33	62	28	<3	<3
Silver	mg/m^3	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL
Zinc	mg/m^3	110	135	75	75	95	107,000	165	170	175
Mercury	mg/m^3	30.8	2.3	1.5	2.3	10	9.2	NDL	11.5	NDL
Thallium	mg/m^3	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL
pH		7.3	6.7	6.4	7.0	7.3	2.4	7.7	3.1	7.4
Chloride	g/m^3						8.90			
Total organic carbon	g/m^3	273.8	167.7	177.1	113.3	245.1	43.1	76.5	55.8	3.9

[a] No detectable level.

TABLE C-3. COAL STORAGE AREA EFFLUENT CONCENTRATIONS, RUN 2

Effluent parameter	Units	Missouri weathered coal F2	Kentucky coal C2	Background BK2
Total suspended solids	g/m^3	5,188	5,408	12
Total dissolved solids	g/m^3	5,500	348	12
Sulfate	g/m^3	4,900	125	4
Iron	mg/m^3	990,000	7,750	70
Manganese	mg/m^3	16,000	20	<10
Free silica	g/m^3	1.3	98.5	3.78
Cyanide	mg/m^3	11	NDL[a]	NDL
BOD_5	g/m^3	<20	<30	<5
COD	g/m^3	2,880	4,625	4
Nitrate as N	g/m^3	0.18	0.16	0.02
Total phosphate as P	g/m^3	NDL	NDL	NDL
Antimony	g/m^3	38	16	<1
Arsenic	g/m^3	12.4	5.5	2.1
Beryllium	mg/m^3	NDL	NDL	NDL
Cadmium	mg/m^3	280	NDL	NDL
Chromium	mg/m^3	NDL	NDL	NDL
Copper	mg/m^3	2,240	180	10
Lead	mg/m^3	310	120	<10
Nickel	mg/m^3	9,600	150	<10
Selenium	g/m^3	70	90	<3
Silver	mg/m^3	NDL	NDL	NDL
Zinc	mg/m^3	31,000	110	70
Mercury	mg/m^3	NDL	NDL	NDL
Thallium	mg/m^3	NDL	NDL	NDL
pH		2.59	6.38	6.79
Chloride	g/m^3	3.20	4.50	2.20
Total organic carbon	g/m^3	6.5	65.6	2.4

[a] No detectable level.

TABLE C-4. COAL STORAGE AREA EFFLUENT CONCENTRATIONS, RUN 3

Effluent parameter	Units	Montana coal A3	New Mexico coal B3	Background BK3	Kentucky coal C3a	Kentucky coal C3b	Kentucky coal C3c	Alabama coal D3	Wyoming coal E3	Missouri weathered coal F3	Illinois coal G3	Missouri fresh coal H3
Total suspended solids	g/m^3	1,048	484	3	2,044	1,140	442	522	1,602	1,946	1,978	228
Total dissolved solids	g/m^3	648	344	32	844	180	196	120	520	4,868	1,020	600
Sulfate	g/m^3	265	133	1	58	55	71	64	148	3,900	525	410
Iron	mg/m^3	2,810	8,560	90	4,290	2,730	1,560	5,320	15,300	1,400,000	17,700	124,000
Manganese	mg/m^3	170	60	20	100	50	80	100	360	13,000	650	4,800
Free silica	g/m^3	3.03	2.08	1.72	2.50	2.05	2.32	2.28	4.38	5.0	3.54	0.58
Cyanide	g/m^3	NDL[a]	NDL	NDL	NDL	NDL	0.018	NDL	NDL	0.006	NDL	NDL
BOD$_5$	g/m^3	5	<5	<5	<5	<5	<5	<5	5	<5	5	<5
COD	g/m^3	1,750	413	4	2,059	784	406	838	1,454	992	2,430	171
Nitrate as N	g/m^3	0.15	0.30	NDL	0.21	0.21	0.22	0.08	0.25	0.14	0.34	0.22
Total phosphate as P	g/m^3	NDL	0.03	0.04	NDL	NDL	NDL	NDL	0.05	0.03	NDL	0.04
Antimony	g/m^3	<0.0005	<0.0005	<0.0005	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.114	0.050	<0.0005
Arsenic	g/m^3	0.016	0.016	0.002	0.027	0.023	0.020	0.014	0.006	0.018	0.005	0.011
Beryllium	mg/m^3	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL
Cadmium	mg/m^3	NDL	NDL	NDL	NDL	NDL	NDL	NDL	10	260	NDL	10
Chromium	mg/m^3	NDL	NDL	NDL	NDL	NDL	NDL	NDL	70	80	NDL	50
Copper	mg/m^3	40	120	60	145	140	80	75	75	2,100	100	85
Lead	mg/m^3	60	45	25	70	80	80	50	100	530	85	100
Nickel	mg/m^3	40	30	10	60	70	60	90	80	6,500	140	350
Selenium	g/m^3	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Silver	mg/m^3	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL
Zinc	mg/m^3	150	205	90	160	125	145	145	475	31,000	390	610
Mercury	mg/m^3	25	1.9	NDL	NDL	NDL	NDL	2.0	NDL	NDL	NDL	NDL
Thallium	mg/m^3	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL	NDL
pH		6.6	6.5	6.4	5.9	5.9	5.9	6.6	7.2	2.7	7.5	3.2
Chloride	g/m^3									1.8		
Total organic carbon	g/m^3	481	158	4.4	700	318	185	231	400	310	692	56

[a] No detectable level.

APPENDIX D

ANALYTICAL METHODOLOGY AND RESULTS, ORGANICS

The highest TOC level (sample A1) from simulation run 1 was used to determine the presence and level of toxic organics. The background sample for run 1 was also analyzed to determine the organic levels in rainfall water. Both samples were extracted with methylene chloride to form two fractions. The first fraction contained basic and neutral compounds and the second, acidic compounds (mainly phenolics). The procedures utilized followed the protocols of the Environmental Monitoring and Support Laboratory which advises and aids the Water Effluent Guidelines Division of EPA (27). Organic components were characterized by a gas chromatograph-mass spectrometer (GC-MS). Primary emphasis was given to identifying those toxic compounds on the EPA Toxic Substances List as per the consent decree (27). Although other compounds were observed, neither time nor funding was available for their identification. The consent decree list contains representative toxic substances, but is not a comprehensive list.

The results of the analyses were reported in the text in Table 23. No phenolic compounds were observed at the greater than or equal to 10-mg/m^3 (greater than or equal to 10-μg/ℓ [ppb])level. Other components of the chromatogram were observed with retention times greater than or equal to 29 min. These components are C_{19} hydrocarbons. In addition, components not on the toxic substances list but possibly present include C_8 hydrocarbons, highly blanched adipates, di-n-butyl peroxide, and isobutylisobutyrate. The presence of the peroxide is considered possible expecially because of the coal-oxygen reaction on the pile surface discussed in Section 3.

The spectra display of the GC-MS analysis is presented in Figure D-1. In this display each toxic substance is identified and corresponds to a particular spectrum and mass/charge ratio per compound. Using acenaphthene from a coal drainage sample as an example, Figure D-2 illustrates spectrum 151. In Figure D-2, the mass/charge ratio of 154 for acenaphthene is observed. Other peaks for compounds with different mass/charge values (dissociation fragments) are observed. The 154 mass/charge ratio of spectrum 151 is established by EPA to represent the level of acenaphthene. The display of mass/charge 154 is presented in Figure D-3. The area of 154 is computed and printed on this figure. This area (1577) is compared with an acenaphthene present. The bottom graph of Figure D-3 is the spectra display.

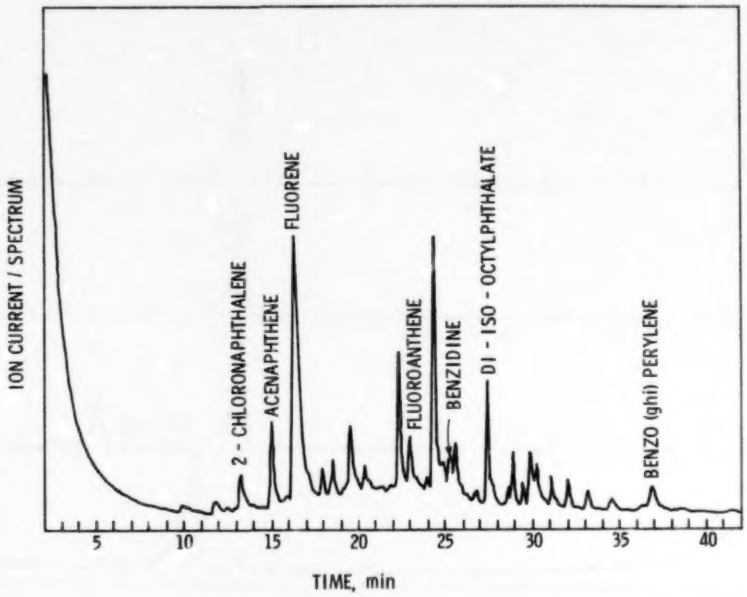

Figure D-1. Spectra displayed of toxic organics within coal leachate and drainage.

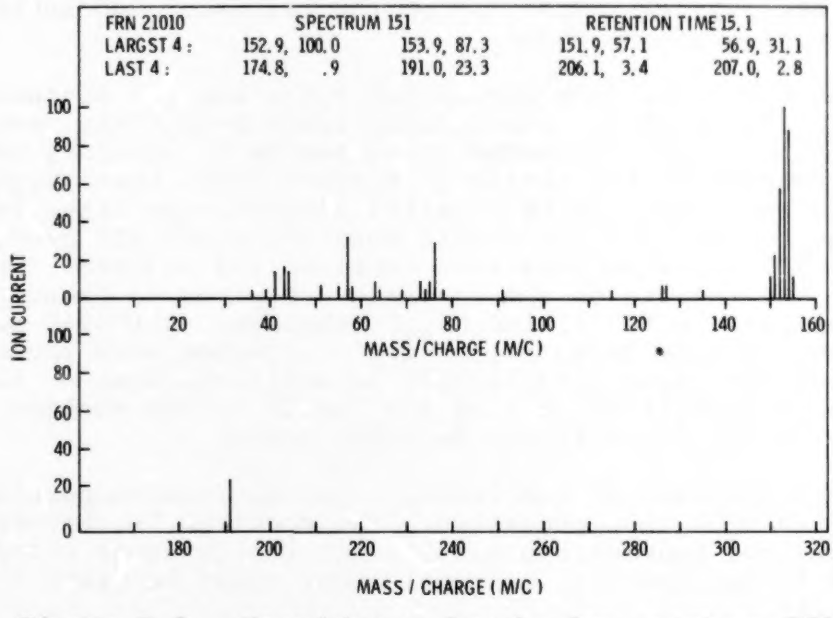

Figure D-2. Mass/charge levels for spectrum 151, (M/C = 154).

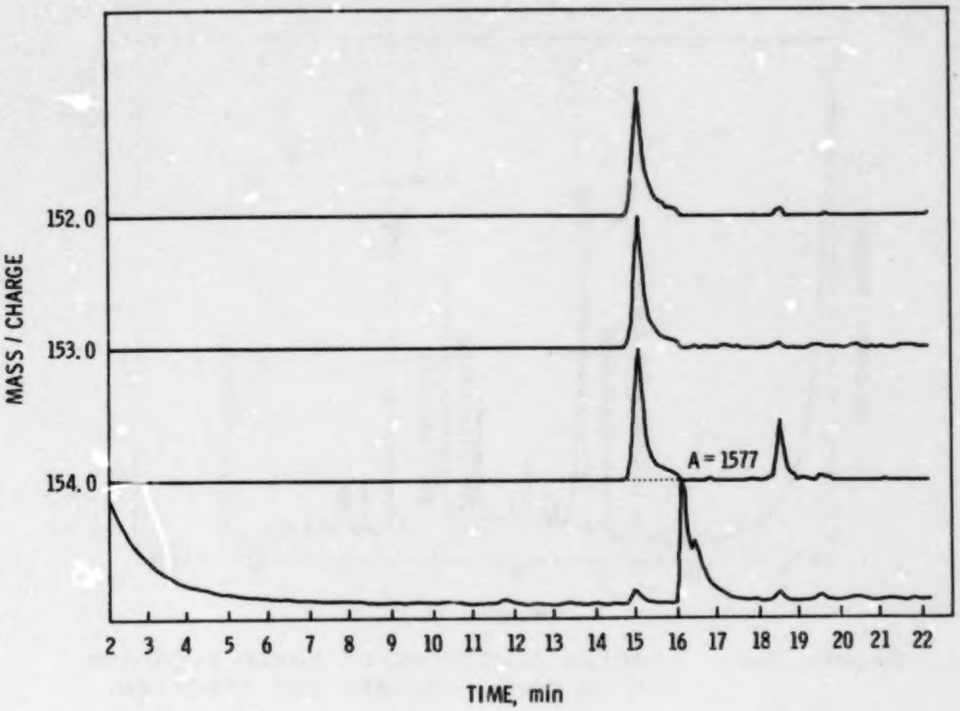

Figure D-3. Ion current levels per mass/charge.

This same analysis was performed on the rainwater and subtracted from this coal drainage value.

The highest TOC level from simulation run 1 was for Montana coal (274 g/m^3). To check the conclusions drawn from these results, another coal area was evaluated using sample C, Kentucky coal. This coal represents the region of Eastern Ohio, West Virginia, and Eastern Kentucky. Three parallel samples were taken for this coal during run 3. The TOC levels were 700 g/m^3, 318 g/m^3, and 185 g/m^3. All three samples were combined and analyzed for toxic organics. The results of the analysis are given in Figure D-4. The highest peak is for di-iso-octylphthalate. Although several organic species were detected, no toxic organics were found at levels above the background level. In addition, some of the toxic species identified at very low levels in the Montana coal leachate were not found in the Kentucky sample.

For the acid fraction of the leachate, no obvious compounds could be identified much less separated. The spectrum is characteristic of a general hydrocarbon oil. Since the internal standard was buried in the spectra, no conclusions could be drawn from these results.

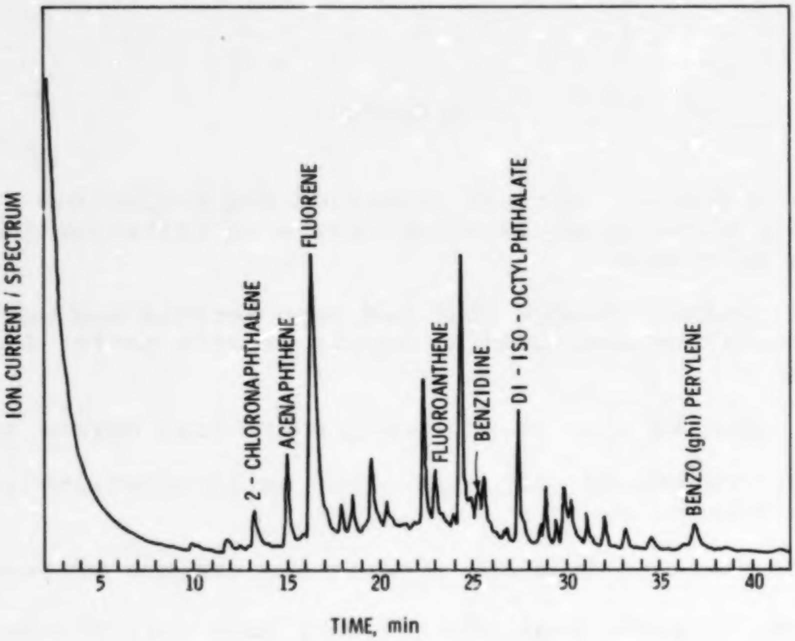

Figure D-4. Spectra display of toxic organics within Kentucky coal leachate.

GLOSSARY

acid mine drainage: Pyritic oxidation and production of an acidic waste in mines which drains in rainwater and runoff into waterways.

activated sludge: Sludge that has been aerated and subjected to bacterial action, used to remove organic matter from wastewater.

aerobic: Able to live or grow only where free oxygen is present.

aged coal: Weathered coal maintained in intermediate and long-term stockpiles.

anaerobic: Able to live and grow in the absence of free oxygen.

anthracite: Highest coal rank; a very hard coal of low volatile content.

aromatic acids: Acidic benzene ring compounds.

base flow: Groundwater flow that passes through the bottom layer of a coal stockpile.

biochemical oxygen demand: Measure of the amount of oxygen consumed in the biological processes that break down organic matter in water.

bituminous: Coal rank just below anthracite; coal of medium volatility.

carbon adsorption: Treatment of liquid organic wastes through a column of activated carbon which adsorbs the organics.

chemical oxygen demand: Measure of the amount of oxygen required to oxidize organic and oxidizable inorganic compounds in wastewater expressed as the amount of oxidant used in a test.

chlorination: Application of chlorine to wastewater for disinfection or oxidation of undesirable compounds.

coagulation: Clumping of particles in order to settle out impurities and produce a soft, semisolid mass of sludge.

coefficient of runoff: Variable used to represent the infiltration/transpiration and other runoff characteristics of various drainage basin terrains.

colloidal particles: Small insoluble nondiffusible particles larger than molecules but small enough to remain suspended in liquid without settling.

dissolved oxygen deficit: Loss of oxygen dissolved in wastewater due to BOD loading from a source.

drainage: Precipitation waters that seep through a coal stockpile.

drainage basin: Watershed catchment area drained by river systems.

electrodialysis: Separation of soluble materials from water by means of their unequal diffusion through permeable membranes enhanced by the application of electrical current.

facultative bacteria: Bacteria capable of living under more than one set of conditions (i.e., conditions other than those usually encountered).

filamentous: Threadlike in structure.

flocculation: Agglomeration of colloidal or suspended matter after coagulation by stirring and collection into small masses or flocs.

flotation: Clarification of wastewater accomplished by using air to float suspended matter to the surface.

free silica: Crystalline silica defined as silicon dioxide (SiO_2) arranged in a fixed pattern (as opposed to an amorphous arrangement).

fresh coal: Coal recently mined and put into storage.

gelatinous: Very viscous; having the consistency of gelatin (jelly).

hydrograph: Chart of runoff levels versus precipitation.

hydrologic: Pertaining to the study and description of the water cycle.

infiltration: Rainfall runoff water that passes through the soil.

interception: Runoff water that is stopped or interrupted in its flow.

ion exchange: Wastewater treatment in which ions of a given species are displaced from an insoluble exchange material by ions of a different species.

Izzard's method: A method consisting of defining a coal pile configuration, dividing it into strips of equal width and slope, and integrating to determine the runoff volume.

leachate: Liquid resulting from water percolating through the coal pile and extracting dissolved materials from it.

lignite: Soft, brown-black coal of high volatility which is very close to peat in structure.

marcasite: Crystallized iron pyrites (FeS_2).

mode: Value that occurs most frequently in a given series.

neutralization: Destruction of the active properties of a wastewater by counteracting the ionic activity, either with a base or acid.

oxalic acid: Colorless, crystalline acid $(COOH)_2$ formed from the oxalis plant.

ozonation: Oxidizing a wastewater with ozone, an allotropic form of oxygen (O_3).

physiographic: Pertaining to the features and phenomena of nature.

protozoa: One-celled animals from the lowest division of the animal kingdom, the phylum of protozoans.

pyrite: Iron sulfide (FeS_2); a lustrous, yellow mineral or any of various metallic sulfides.

pyritic oxidation: Chemical reaction of pyrite with oxygen.

rational method: Hydrologic technique for determining the runoff rate from a drainage basin.

reverse osmosis: Wastewater treatment in which the contaminated liquid is pressurized through a semipermeable membrane to separate water from pollutants.

runoff: Rainfall that flows from and out of the drainage basin.

sedimentation: Settling out of solids by gravity.

slacking: Rapid changes in coal pile moisture content caused by alternating sun and rain.

subbituminous: Brown-black coal of low to medium volatility.

surface flow: Storm-induced runoff waters.

total organic carbon (TOC): Level of carbon (excluding carbonates) within a wastewater.

transpiration: Process by which rainfall water gives off moisture to the atmosphere.

trickling filter: Device for the biological or secondary treatment of wastewater consisting of a bed of rocks or stones that support bacterial growth; wastewater is trickled over the bed enabling the bacteria to break down organic wastes.

unicellular: Having or consisting of a single cell, such as protozoa.

variance ratio: Ratio of the highest to lowest average value of coal analyses.

water quality criteria: Levels of pollutants that affect the suitability of water for a given use.